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CENTER OF NUCLEAR ENERGY IN AGRICULTURE

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Greenhouse gas emission on Brazilian beef production: from experimental data to farm-scale modeling

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DEDICATION

to **ELIZA** and **NILSON**,

My “life advisors”

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ABSTRACT

MAZZETTO, A. M. **Greenhouse gas emission on Brazilian beef production:** from experimental data to farm-scale modeling. 2014. 95 f. Thesis (Doctorate) – Center of Nuclear Energy in Agriculture, University of São Paulo, Piracicaba, 2014.

The emission of greenhouse gases (GHG) is currently intensely debated issue. Countries with reduction targets of GHG emissions have developed studies to understand the processes and reduce the emissions. Farming is the main source of GHG emissions in Brazil. Among the main products of Brazilian agriculture is cattle, handled mainly in the extensive system, where animals are slaughtered at an average of three to four years and grassland receives little or no cultural tract. Quantification and monitoring of GHG emissions in agricultural systems enable the evaluation of the degree of impact on the environment. This thesis discussed the main sources of greenhouse gases emissions in animal husbandry and the guidelines on research to evaluate alternative sustainable systems of beef production. The main results are the emission factors for tropical conditions from various sources, such as faeces (Chapter 3) and urine (Chapter 4) from the animals, as well as the application of nitrogen fertilizer and lime on pasture (Chapter 5). The climate proved to be a key factor in the control of greenhouse gases, mainly methane (CH_4) from the faeces of animals. The emission factors obtained for cattle faeces were 0.03 and 0.08 kg CH_4 head^{-1} year^{-1} (average) for subtropical and tropical climates, respectively. The use of a generic emission factor in Brazil is not the best option. More studies are needed in different regions to determine the impact of climate on GHG emissions. The emission factor for nitrous oxide (N_2O) from urine was 0.25 % of total N applied (average), significantly lower than the default factor recommended by the IPCC. The use of nitrification inhibitors under tropical conditions is not recommended, since there were no positive results in reducing the emission of N_2O from urine. The use of nitrogen fertilizer led to high N_2O emissions, however, the dry matter production of forage also increased with fertilizer application. The balance between dry matter production and N_2O emission shows that the application of nitrogen fertilizer can contribute significantly to reducing pasture area, with a total reduction of up to 40 %. Mathematical modeling of the data was also performed, simulating beef production under extensive management in different scenarios for the studied area (Chapter 6). The CH_4 emission decreased, while the emission of carbon dioxide (CO_2) and N_2O increased due to the simulated intensification. The simulation showed that the intensification in beef production results in lower GHG emissions per kg of beef. Reductions may reach 2 to 57%, depending on the scenario. The intensification also contributes to the reduction of the total area and length of the production cycle. These results show that the intensification practices are a potential mitigation option for the beef sector.

Keywords: Cattle. Greenhouse gases. Emission fator. Intensification. Climate.

RESUMO

MAZZETTO, A. M. **Emissão de gases do efeito estufa provenientes da produção de carne no Brasil:** de dados experimentais a modelagem matemática. 2014. 95 f. Tese (Doutorado) – Centro de Energia Nuclear na Agricultura, Universidade de São Paulo, Piracicaba, 2014.

A emissão de gases do efeito estufa (GEE) é assunto intensamente debatido atualmente. Países com metas de redução na emissão destes gases têm desenvolvido estudos visando entender os processos e reduzir as emissões. A agropecuária é a principal fonte de emissão de GEE do Brasil. Entre os principais produtos da agropecuária brasileira está o gado de corte, manejado principalmente no sistema extensivo, onde os animais são abatidos em média aos três a quatro anos e a pastagem recebe pouco ou nenhum trato cultural. A quantificação e o monitoramento das emissões de GEE em sistemas agropecuários possibilitam a avaliação do grau de impacto sobre o ambiente. Nesta tese foram discutidas as principais fontes de emissão de gases na pecuária e as diretrizes necessárias na pesquisa para avaliar alternativas sustentáveis dos sistemas de produção da carne. Os principais resultados obtidos são os fatores de emissão para as condições tropicais de diversas fontes, como fezes (Capítulo 3) e urina (Capítulo 4) dos animais, assim como da aplicação de fertilizante e calcário a pasto (Capítulo 5). O clima mostrou-se como um fator chave no controle de GEE proveniente das fezes dos animais, principalmente metano (CH_4). Os fatores de emissão para fezes bovinas obtidos foram de 0,03 e 0,08 kg CH_4 cabeça^{-1} ano^{-1} (média), para os climas subtropical e tropical, respectivamente. O uso de um fator de emissão genérico para o Brasil não é a melhor opção, sendo necessários estudos em diferentes regiões para determinar o impacto do clima na emissão de GEE. O fator de emissão de N_2O proveniente da urina foi de 0,25% do total de N aplicado (media), significativamente menor que o fator *default* recomendado pelo IPCC. O uso de inibidores de nitrificação nas condições tropicais não é recomendada, visto que estes não foram efetivos na redução da emissão de óxido nitroso (N_2O) proveniente da urina dos animais. O uso de fertilizante nitrogenado levou a um aumento da emissão de N_2O, porém, a produção de massa seca da forrageira também aumentou com a aplicação do fertilizante. O balanço entre produção de massa seca e emissão de N_2O mostra que a aplicação de fertilizante nitrogenado pode contribuir significativamente com a redução da área de pasto, com redução total de até 40%. Também foi realizada a modelagem matemática dos dados obtidos, simulando a produção de carne sob manejo extensivo em diversos cenários (Capítulo 6). A emissão de CH_4 diminui, enquanto a emissão de dióxido de carbon (CO_2) e N_2O aumentaram devido as práticas de intensificação simuladas. A simulação mostrou que a intensificação na produção de carne bovina resulta em menor emissão de GEE por kg de carne produzida. As reduções podem chegar de 2 a 57%, dependendo do cenário. A intensificação também contribui com a diminuição da área total e tempo do ciclo de produção. Estes resultados mostram que a intensificação é uma potencial prática de mitigação para a produção de carne.

Palavras-chave: Gado. Gases do efeito estufa. Fator de emissão. Intensificação. Clima.

CONTENTS

1. INTRODUCTION

According to researchers, in the year 2050 about 10 billion people will inhabit the planet Earth. At the same time there is a global concern with increasing temperature due to the greenhouse effect and the increasing concentration of greenhouse gases (GHG) in the atmosphere. In theory, the higher the number of people, the higher their demand for food and the associated gas emissions from the production of these foods, besides the daily actions of people. Solutions of public transport, clean energy and others in reduce GHG emission has recently emerged, but we still do not know well enough the food production systems to determine actions aiming the mitigation of GHG emissions with high productivity.

The beef production is considered one of the main sources of GHG emissions. The study of the physiology of the ruminant and plant and their interaction has received considerable attention, especially in Brazil, which is a leading producer of beef in the world. Only recently studies related to GHG emissions from beef production has been initiated. As an important emitter of GHG, the livestock sector also has a large potential to reduce its emissions. It became necessary to evaluate all sources of GHG in the beef production chain to propose changes aiming the reduction of GHG emission.

This thesis contributes to the knowledge about the sources of GHG in the Brazilian beef production, calculating the emission factors for tropical conditions of the main sources of GHG through field and laboratory experiments. For the evaluation of mitigation measures was necessary to extrapolate the data obtained in the field at a farm scale using mathematical models. The parameterization and development of models for tropical conditions are still little explored and is an important topic in systems evaluation.

This thesis is divided into the following chapters: Literature Review (Chapter 2); Emission of GHG from bovine faeces (Chapter 3); Emission of GHG from bovine urine (Chapter 4); Emission of GHG from intensification techniques for beef production (Chapter 5); Mathematical modelling of different animal production systems (Chapter 6); Final considerations (Chapter 7).

2. GENERAL REVIEW

2.1 Global warming and greenhouse gas emission

The planet Earth has always gone through natural cycles of cooling and warming, with periods of intense volcanic activity. Events like these have led to the formation of a gas layer that covers the planet, causing a natural greenhouse effect. The term "global warming" refers to the expansion of the greenhouse effect caused primarily by increased atmospheric concentrations of certain gases. Among the greenhouse gases (GHG), the most significant are carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) emitted by the intensification of human activity (NAE, 2005). This progressive increase in the concentration of GHG in the atmosphere increases the retention of solar radiation, mostly in the infrared range, causing global temperature increase (LAL., 1998; COX et al., 2000). The Intergovernmental Panel on Climate Change (IPCC, 2007) have shown that between 1900 and 2100 the global temperature could increase between 1.4 and 5.8 °C, which represents a warming faster than that detected in the twentieth century. The adverse consequences of this phenomenon, manifested as climate change, are among the main environmental concerns of today faced by the population of the Earth.

Agricultural practices are important sources of GHG, particularly CH_4 and N_2O. Emissions do not show a similar pattern across countries. The ratio of the contributions of GHG from the burning of fossil fuels, agriculture and land use change in Brazil have different profiles from those observed globally. In Germany and Ireland agriculture accounts for 10 % and 35%, respectively, of total emissions of these countries (DESTATIS, 2004), while in Brazil this value reaches more than 70% (agriculture and deforestation) (CERRI et al., 2009). These data clearly show that agriculture represents a large portion of GHG emissions in Brazil. The livestock sector has considerable GHG emissions directly (enteric fermentation and manure) plus numerous other indirect emissions from agriculture (production of animal feed), the change of land use (through deforestation for opening new areas of pasture), besides fossil fuels (transport operations and processes). Thus it is necessary to determine specific emission factors that reflect the reality of the conditions found in Brazil enabling accurate quantification of GHG emissions.

2.2 Livestock: Sources and Sinks

The quantification of GHG emissions from the livestock industry is complex because not merely determine the emission from enteric fermentation of cattle, as are necessary calculations for manure management and land use change (CERRI et al., 2009). The main factors that contribute to emissions are related to enteric fermentation, solid and liquid waste, use of nitrogen fertilizer and limestone.

2.2.1 Sources

The enteric fermentation results in large emissions of CH_4 to the atmosphere. Methane production is part of normal ruminant digestive processes and occurs in their pre-stomach (rumen). Fermentation in rumen is an anaerobic process that converts cellulosic carbohydrates into short-chain fatty acids, mainly acetic, propionic and butyric. This transformation produces CO_2 and CH_4, which are voided by eructation and respiration (PRIMAVESI et al., 2004). Methane in enteric fermentation represents a pathway of hydrogen (H_2) removal produced during microbiological metabolism. In the process of carbohydrate oxidation via glycolysis, NAD^+ is reduced to NADH then re-oxidized to NAD^+ allowing fermentation to continue. Anaerobic conditions in NAD^+ regeneration occur by electrons transfer to acceptors other than oxygen. The primary electrons acceptor is the reduction of CO_2 to CH_4 (MCALLISTER; NEWBOLD, 2008). Accordingly, CH_4 production in rumen is directly related to animal diet quality, ranging from 4 to 9% of food gross energy intake (LIMA et al., 2006). Faeces are potential sources of CH_4. The urine promotes mainly the emission of N_2O (LIMA et al., 2006). CO_2 emissions in the livestock industry are mainly associated with the use of lime to correct the pH of the soil under cultivation of fodder (WEST; MARLAND, 2002). More details about the processes related greenhouse gas emissions are found in the reviews of each chapter of the thesis.

2.2.2 Carbon Sink and mitigation options

Soils under natural vegetation shows stable carbon stock due to the dynamic equilibrium of CO_2 emissions from soil and amount of organic matter from vegetation. When the soil is cultivated this balance is changed. In pastures, the death roots are the main source of C to the soil. The use of forage grasses increases the stock and distributes C in subsurface soil (MAIA et al., 2010). Maia et al. (2009) concluded that well-managed pastures in Mato Grosso and Rondônia can provide an increase in organic carbon content of the soil, promoting carbon sequestration. No soil disturbance results in low CO_2 flux to the atmosphere due to lower mineralization of soil organic matter (SOM) (BAYER et al., 2000), and the large supply of nutrients allows an increase in content SOM in long-term (CARNEIRO et al., 2008). Currently, the vast majority of pastures in Brazil are degraded. The improvement of these pastures is an alternative to mitigate emissions of greenhouse gases by sequestering C.

The main actions to mitigate GHG emissions in beef sector targets CH_4 from enteric fermentation and N_2O from urine and fertilizer. One strategy to mitigate greenhouse gases is the use of improved silage (low NDF, high carbohydrate concentration, change of C4 to C3 grass) that can reduce the production of CH_4 (BEAUCHMIN et al., 2008). In addition to preventing the emission of gases, the correct balance in the diet can provide more efficient weight gains, reducing the emission of CH_4 with decreasing age at slaughter (ECKARD et al., 2010). The strategies for N_2O mitigation can roughly be divided into two types (i) increasing the N use efficiency and (ii) reducing the N_2O production per unit of N (OENEMA et al., 2001). These include improving fertilizer efficiency (Brown et al., 2005), optimizing methods and timing of applications (DOSCH; GUTSER, 1996), using ammonium-based fertilizers rather than nitrate-based ones (DOBBIE; SMITH, 2003) and employing chemical nitrification inhibitors (MERINO et al., 2002; MACADAM et al., 2003). The nitrification inhibitors (NI) are well studied in the literature. NIs are used in agriculture to increase the efficiency of nitrogen fertilizers and minimize nitrification and leaching of NO_3^- by keeping the N applied as NH_4^+ (BRONSON et al., 1992). Among the various NIs, the dicyandiamide (DCD) has proven effective by decreasing the N_2O emissions from fertilizers and animal waste (WILLIAMSON; JARVIS, 1997; DI; CAMERON, 2002; DOBBIE; SMITH, 2003; BARTH, 2009; ZAMAN et al., 2009).

The intensification of animal production may also contribute to the mitigation, reaching 30% reduction in total emission per unit of product (GERBER et al., 2013). Other mitigation options can still be evaluated, such as restricting grazing during the rainy season, where the soil is soggy, increasing anaerobic and N_2O emission (LUO et al., 2008). There are also more advanced options being studied but are not yet being implemented, as elimination of rumen protozoa and vaccination to reduce methanogenesis (MCALLISTER; NEWBOLD, 2008).

2.2.3 Balance

The environmental impact of a product in terms of GHG emission is called "carbon footprint" and is expressed in grams or tons of CO_2eq per functional unit. The "carbon footprint" is defined as the overall processes of GHG emissions caused directly or indirectly by an individual, organization or product. Obtaining the "carbon footprint" of meat production involves the measurement of all sources of GHG emissions, less carbon fixed in the soil by the grass.

In Brazil the GHG emissions by manure, urine, lime and fertilizer from extensive beef production are little known. Scientific research is important in determining the GHG emission factors, since the methodologies and emission factors proposed by the IPCC are based on studies made in temperate countries and do not represent the reality of tropical countries such as Brazil. Through this quantification and monitoring of GHG emissions in agricultural systems is possible to assess the impact on the environment caused by inappropriate land use and mishandling of animals and crops. From this assessment, mitigation practices can be proposed, in order to make the beef production more sustainable. The adoption of such measures in livestock could confer upon Brazil international credibility in the fight for environmental preservation, making Brazilian beef more valued and accepted in all international markets.

2.3 Modelling

A mathematical model is made up of one or more equations in order to represent the behavior of systems or natural phenomena. The models allow the evaluation of a system as a whole, with sensitivity to detect the consequences of changes in input parameters. Currently models are needed to test hypotheses, to challenge dogmas, project future situations and assist the decision-making. Whole-farm models of livestock systems should therefore be able to give an accurate representation of the internal cycling of materials and their constituents as well as the exchange of materials and nutrients between the farming system and its environment. The goal is to count all the balance of gases to show, over time, trajectories of increase or decrease in net emissions. Calculations on farm scale are useful to explore mitigation options for individual farms. However, for fulfilling national reduction targets there is a need to ensure that such mitigation options are also reflected in the national emission inventories.

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3. TEMPERATURE AND MOISTURE AFFECT METHANE AND NITROUS OXIDE EMISSION FROM BOVINE MANURE PATCHES IN TROPICAL CONDITIONS

Abstract

Animal production systems are important sources of greenhouse gases (GHG), especially methane (CH_4) and nitrous oxide (N_2O). Brazilian beef production is almost exclusively (more than 90%) pasture-based. GHG emissions from faeces deposited in pastures have been extensively studied in temperate climates, but there are no emission data for tropical conditions. The aim of this study was to examine the effects of tropical temperature and moisture conditions on GHG emission from manure. We hypothesized that periodical rainfall and high temperature on tropical climates can increase the GHG emission from faeces by maintaining an anaerobic environment within the faeces as compared with temperate conditions. We measured the emission of CH_4 and N_2O from cattle faeces in two different field sites in Brazil: São Paulo (subtropical) and Rondônia (tropical), as well as under controlled conditions. Emissions of CH_4 emissions from faeces ranged from 117 to 1007 mgC-CH_4 m^{-2} h^{-1}. In the field, summer emissions were 2.9 (São Paulo) and 2.5 (Rondônia) times higher than winter ($p < 0.05$). In controlled conditions, prolonged moisture conditions at high temperature (35°C) resulted in higher emissions ($p < 0.05$) than the no-rewetted treatment (2831 and 1781 mgCH_4 m^{-2}, respectively). Emission factors determined were 0.02 and 0.05 kg CH_4 $head^{-1}$ $year^{-1}$ (winter and summer São Paulo, respectively) and 0.06 and 0.10 kg CH_4 $head^{-1}$ $year^{-1}$ (winter and summer Rondônia, respectively), significantly lower than the IPCC default value of 1 kg CH_4 $head^{-1}$ $year^{-1}$. N_2O emission from faeces was lower than the control at the Rondônia site during the summer, with net negative fluxes. CH_4 emissions from faeces showed results slightly higher than others studies in temperate climates, and N_2O emissions were lower, with net negative fluxes at the tropical site. We conclude that climate is a strong factor controlling GHG emission from faeces, and more studies are recommended in other Brazilian regions to determinate specific emission factors, rather than use a generic or IPCC default emission factor.

3.1 Introduction

The Brazilian cattle herd is massive, reaching about 200 million heads. Brazil is the second largest exporter of beef, responsible for 15% of beef production worldwide (FAO, 2012). More than 90% of Brazilian beef production occurs on pasture, with a low grazing intensity (1 head ha^{-1}) (ANUALPEC, 2010). Extensive cattle breeding occupies 48% of arable land. Most of the slaughtered animals (60%) for beef production are 4 years old steers, with an average weight of 450 kg (FERRAZ; FELICIO, 2010).

Ruminant animals play an important role in greenhouse gas (GHG) emission of methane (CH_4) and nitrous oxide (N_2O) into the atmosphere. Emissions occur mainly through enteric fermentation and cattle manure (faeces and urine) deposited in pastures. Although there is extensive literature on animals and production rates of methane and nitrous oxide under temperate conditions (SAGGAR et al., 2004; ECKHARD et al., 2010), much less is known for tropical conditions. The excreta from grazing animals can give rise to “hot-spots” for GHG emission. The warm and moist conditions in cattle manure create an optimal microenvironment for the anaerobic microorganisms that produce CH_4 (SAGGAR et al., 2004) and N_2O (ALLEN et al., 1996; FLESSA et al., 1996). These faeces are decomposed and subject to various factors that may influence the extent of GHG emission, such as temperature and rainfall.

Given the large number of animals and lack of information related to GHG emission from faeces, we examined the emission of CH_4 and N_2O from faeces in Brazil, in two different regions: São Paulo (subtropical climate) and Rondônia (tropical climate). We hypothesized that periodical rainfall and high temperature in tropical climates would increase the GHG emission by maintaining an anaerobic environment within the faeces. We also hypothesized that the studied regions would have different patterns of emission because of different climate.

3.2 Material and Methods

3.2.1 Field experiments

The experimental pastures were not grazed by livestock before or during the experiment and had not received any nitrogen fertilizer for five months prior to the experiment. The first experiment was carried out from 27 July to 26 August 2011 (winter) and 31 January to 29 February of 2012 (summer) at the University of São Paulo, Piracicaba, SP, Brazil (22°42'07''S; 47°37'17''W) under subtropical climatic conditions (Cwa-Koppen climatic classification). The average air temperature and total precipitation were 19°C and 50 mm (winter); 25°C and 139 mm (summer) (Figure 1).-The second experiment was carried out from 09 June to 10 July 2012 (winter) and 09 November to 10 December of 2012 (summer) at Agropecuária Nova Vida, Ariquemes, RO, Brazil (10°10'05''S; 62°49'27''W) under tropical climatic conditions (Aw-Koppen climatic classification). The average air temperature and total precipitation were 32°C and 7 mm (winter); 29°C and 250 mm (summer) (Figure 1). Meteorological data were recorded at the nearest meteorological station (rainfall and air temperature), which was within 1 km of both field sites.

3.2.2 Set up of the field experiments

The soil from SP experiment was classified as a Nitisol (FAO, 1998), with sandy loam soil texture, while the soil from RO experiment was classified as Oxisol. Sand, clay, silt content, pH and bulk density were determined according to Embrapa (1979) and Anderson and Ingram (1989). The total soil C and N were determined by dry combustion (NELSON; SOMMERS, 1996), through a CN elemental analyzer (LECO @2000). Soil mineral N content was determined by extraction with 2 M KCl with a 1:2 ratio of soil and extractant (BREMMER; KEENEY, 1966). Soil extracts were filtered and stored at 4°C. Concentrations of NH_4^+ and NO_3^- in the extracts were determined by automated flow injection analysis (FIA) (RUZICKA; HANSEN, 1981). Soil properties (upper 10 cm) from the start of the experiment are shown in Table 1.

Faeces were collected from a group of 10, three year old steers (*Nellore*), with an average weight of 450 kg, directly before the start of the experiments, and thoroughly mixed before application. The steers were grazing pasture (*Brachiaria decumbens)* supplemented with mineral salts. The selected area in each site was divided in 10 plots, each 1 x 1 m and assigned to two treatments (with faeces, labeled as "WF" and a control with no faeces, labeled as "NF") with five replicates, laid out as a randomized complete block design. Plots consisted of a chamber area (0.064 m^2) and adjacent area for faeces sampling (0.05 m^2). The chambers were installed and remained in soil during 30 days. After this, chambers were removed and installed again in the same area in other season. Each dung sample was applied at the rate of 8 kg m^{-2} (2.50 kgC m^{-2}; 0.13 kg N m^{-2}; water content: 85%). These rates represent values observed in extensive systems (GONZÁLEZ-AVALOS; RUIZ-SUÁREZ, 2001; ORR et al., 2012) and by our own observations in the field.

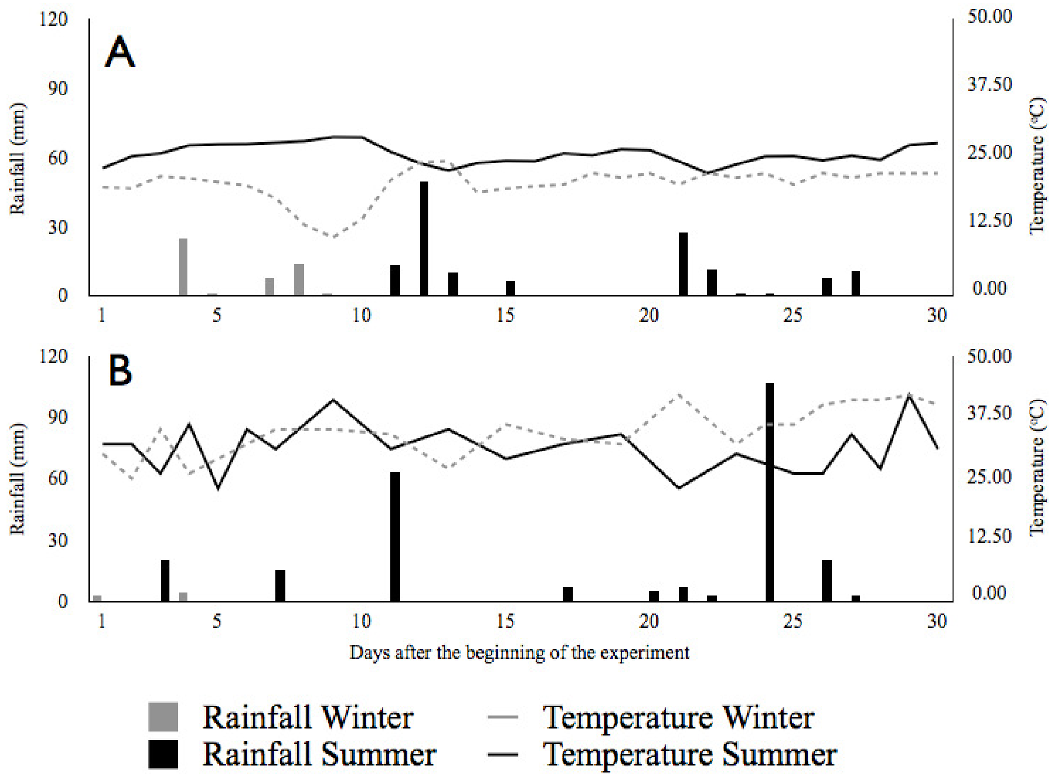

Figure 1 – Climatic data from the study sites, during two different seasons. (A) São Paulo; (B) Rondônia

Table 1 – Soil proprieties (0-10 cm) at the beginning of the two field experiments during winter and summer

		Sand	Clay	Silt	pH	Density	C	N	NO_3^-	NH_4^+
		-----------% -------				g m^{-3}	g $kgdrysoil^{-1}$		mgN $kgdrysoil^{-1}$	
SP	Winter	35	30	35	5.4	1.60	28.3	2.1	8.1	3.1
	Summer	37	23	40	5.6	1.60	30.3	2.9	18.1	5.8
RO	Winter	62	30	8	4.9	1.50	25.5	2.2	2.5	5.2
	Summer	65	25	8	5.0	1.50	27.3	3.0	1.3	2.3

SP: São Paulo state; RO: Rondônia state

3.2.3 Flux measurements

A closed static chamber technique (JONES et al., 2005) was used for estimating CH_4 and N_2O emission. At the field site, non-vented steel chambers (28 cm diameter, 13 cm height) were installed two days before the first sampling. The chambers were inserted to a depth of up to 3 cm to ensure an airtight seal. At the time of sampling, lids were placed on top of the chambers and a seal was achieved via water filled groove on the chamber that the lid fitted in to. There were 17 sampling occasions: daily during the first week, followed by three times a week for the next two weeks and twice in the last week of the experiment. Gas sampling was normally carried out between 09:00 and 11:00. Samples were collected at 0, 10 and 20 minutes after the chamber were closed. A 20-ml syringe was used to collect the gas samples from the chambers, which were then placed in pre-evacuated 13 ml headspace vials using a hypodermic needle. The glass vials had a chloro-butyl rubber septum (Chromacol). Samples were analysed for CH_4 and N_2O within 7 days after collection by gas chromatography (GC - Shimadzu 2014). Total GHG emissions from WF and NF treatments were estimated by calculating cumulative fluxes over an experimental period of 30 days in both experiments.

Adjacent to each flux chamber were assigned plots that also received the same faeces rate. Faeces were sampled on days 1, 7, 15, 22 and 30. Water filled pore space (WFPS) of the soil and moisture of the faeces were calculated gravimetrically.

3.2.4 Potential production of CH_4 and N_2O

We also investigated how temperature and moisture influenced the production of methane and nitrous oxide in soils incubated in laboratory. Soil (0-10 cm) was collected from the same place of São Paulo field experiment, sieved at 2 mm, mechanically homogenized and then stored at 4ºC for one week prior to the beginning of the experiment. Faeces were collected from the same animals from the São Paulo field experiment, and following homogenization surface-applied at the rate of 16 kg m^{-2}. Faeces and soil were incubated in glass containers (15 x 10 x 5 cm), with air-tight lids. Headspace samples were collected with a 20 mL syringe after a 60 minutes closure period of the containers. Except for the periods when samples were taken, the containers were left open. Sampling was continued until emissions receded to background levels. The experimental design included three factors and two treatments (2 x 2 x 2), as follows - (1) WF and NF; (2) temperature (25 and 35°C); and (3) moisture (rewetting the faeces every day, simulating an periodical rainfall, labeled as “Moist” and non-rewetting, labeled as “Dry”). Each treatment had five replicates.

3.2.5 Statistical analyses

Data were verified for normal distribution, treatment means for daily CH_4 and N_2O fluxes and cumulative flux over the period of the experiment were compared using one and two-way analysis of variance. Differences between individual treatments were determined using a Tukey test. All significances mentioned in the text were significant at $p \leq 0.05$.

3.3. Results

3.3.1 CH_4

3.3.1.1 Field experiments

The WF treatment showed a maximum CH_4 emission rate on the first day of sampling in São Paulo (2.8 and 6.1 mg CH_4-C m^{-2} h^{-1}, in winter and summer, respectively) (Figure 2). In Rondônia, the peak emission was in the first day during winter (9.9 mg CH_4-C m^{-2} h^{-1}) and in the third day during summer (7.2 mg CH_4-C m^{-2} h^{-1}). There were other peaks that were different from NF during summer in Rondônia (days 7, 11 and 21) (Figure 2). Table 2 shows that faeces moisture during summer increased because of rainfall events, especially in Rondônia.

At both sites cumulative emissions from the WF treatment were statistically higher in summer than winter (Table 3). Emissions from the NF treatment remained at background levels, except for the summer in Rondônia, where a significantly higher amount of CH_4 emission was detected (202 mgCH_4-C m^{-2}), compared to the NF treatment in winter.

To calculate the emission factor of faeces emission, we considered one animal defecating 10 kg (wet weight) of faeces per day in 10 events (1 kg per event), which represent values observed in extensive systems (GONZÁLEZ-AVALOS; RUIZ-SUÁREZ, 2001; ORR et al., 2012) and by our own observations in the field. The calculated emission factors for the studied situations were 0.02 (winter) and 0.05 (summer) kg CH_4 head^{-1} year^{-1} for São Paulo. For Rondônia, the values were 0.06 (winter) and 0.10 (summer) kg CH_4 head^{-1} year^{-1}.

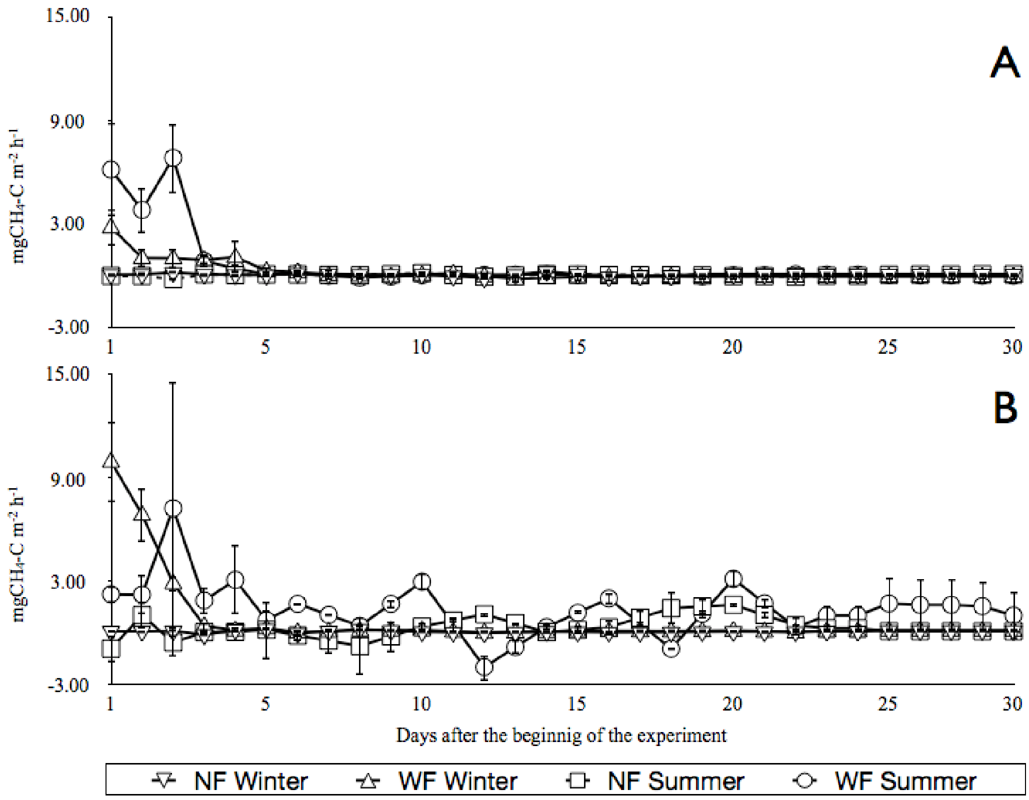

Figure 2 – CH_4 emission from the study sites, in two different seasons. (A) São Paulo state; (B) Rondônia state. The error bars denote the standard deviation

Table 2 – Faeces moisture (%) and soil water filled pore space (WFPS-%) in the soil (0-10 cm) at the two field experiments during winter and summer

	São Paulo				Rondônia			
	Faeces		Soil WFPS		Faeces		Soil WFPS	
Day	Winter	Summer	Winter	Summer	Winter	Summer	Winter	Summer
1	86	84	39	61	88	83	59	70
7	77	67	36	40	30	76	55	72
15	60	71	34	73	23	77	50	84
22	42	12	45	39	20	73	44	82
30	15	24	36	55	12	80	34	86

3.3.1.2 Potential production of CH_4 and N_2O

The cumulative fluxes and statistical differences are shown in Table 4. At high moisture (Moist treatment) and high temperature (35°C), high emission was found. At 25°C there was no effect of moisture on CH_4 emission from WF treatment. At 35°C, the faeces were dried in four days for the Dry treatment (lowest emission from faeces). NF emissions remained at background levels until the end of the experiment in all treatments.

3.3.2 N_2O emissions

In the field experiments, emissions of N_2O were highly variable (Figure 3). There was a statistically significant difference between N_2O emissions from WF and NF only in the Rondônia state, during the summer (Table 3), where the WF treatment was a larger N_2O sink than the NF treatment (-22.6 and -18.7 mg N_2O-N m^{-2} respectively). Negative fluxes of N_2O were commonly found in our experiment, with peak uptakes of -0.12 and -0.01 mg N-N_2O m^{-2} h^{-1} (Rondônia and São Paulo, respectively). Winter emission from the NF treatment was statistically higher than summer emission at both sites (Table 3). In the laboratory experiment, faeces were a source of N_2O only in the Moist treatment (Table 4).

Table 3 – Cumulative CH_4 and N_2O emissions from faeces and unmanured control at field studies, during two seasons

			CH_4-C				N_2O-N			
			----------mg m^{-2}----------							
Field Site	Season	Treatment	CE		S.D.	C.V.	CE		S.D.	C.V.
SP	Winter	NF	0.3	bB	0.20	66.7	7.7	aA	0.80	10.0
		WF	118.0	aA	44.50	38.0	5.1	aB	1.90	37.3
	Summer	NF	-0.9	bB	0.70	81.1	2.1	aB	1.20	59.6
		WF	351.0	aA	120	34.3	1.0	aB	3.90	378.0
RO	Winter	NF	16.7	bC	3.80	22.6	-4.7	aB	3.70	78.6
		WF	397.0	aB	50.60	12.7	16.9	aA	9.40	55.4
	Summer	NF	201.0	bC	137	67.7	-18.7	aC	5.00	26.4
		WF	1007.0	aA	242	24.0	-22.6	bB	88.60	392.0

SP: São Paulo state; RO: Rondônia state; NF: No-faeces (control) treatment; WF: with faeces; C.E.: Cumulative Emission; S.D.: Standard Deviation; C.V.: Coefficient of Variation; CO_2eq: CO_2 equivalent. Means followed by the same letters in columns are not statistically different (Tukey, $p < 0.05$). Small letters show comparison between the treatments in the same field site and season, while capital letters show comparison between seasons in the same field site.

Table 4 – Cumulative emissions obtained in controlled conditions studies

Temperature (°C)	Moisture	Treatment	CH_4-C				N_2O-N			
			---mg m^{-2}---							
			CE		S.D.	C.V.	CE		S.D.	C.V.
25	Dry	NF	5.5	c	3.7	66.7	5.5	c	1.8	33.3
		WF	2958.0	a	587.0	20.0	27.5	bc	25.6	93.3
	Wet	NF	7.3	c	3.7	50.0	11.0	c	1.8	16.7
		WF	2788.0	a	306.0	11.0	218.0	a	57.0	26.0
35	Dry	NF	11.0	c	5.5	50.0	-7.3	c	3.7	50.0
		WF	1781.0	b	220.0	12.4	7.3	c	1.8	25.0
	Wet	NF	-3.7	c	3.7	100.0	12.8	c	1.8	14.3
		WF	2832.0	a	739.0	26.1	77.0	b	39.0	50.0

NF: No-faeces (control) treatment; WF: with faeces; C.E.: Cumulative Emisson; S.D.: Standard Deviation; C.V.: Coefficient of Variation. Means followed by the same letters in columns are not statistically different (Tukey < 0.05).

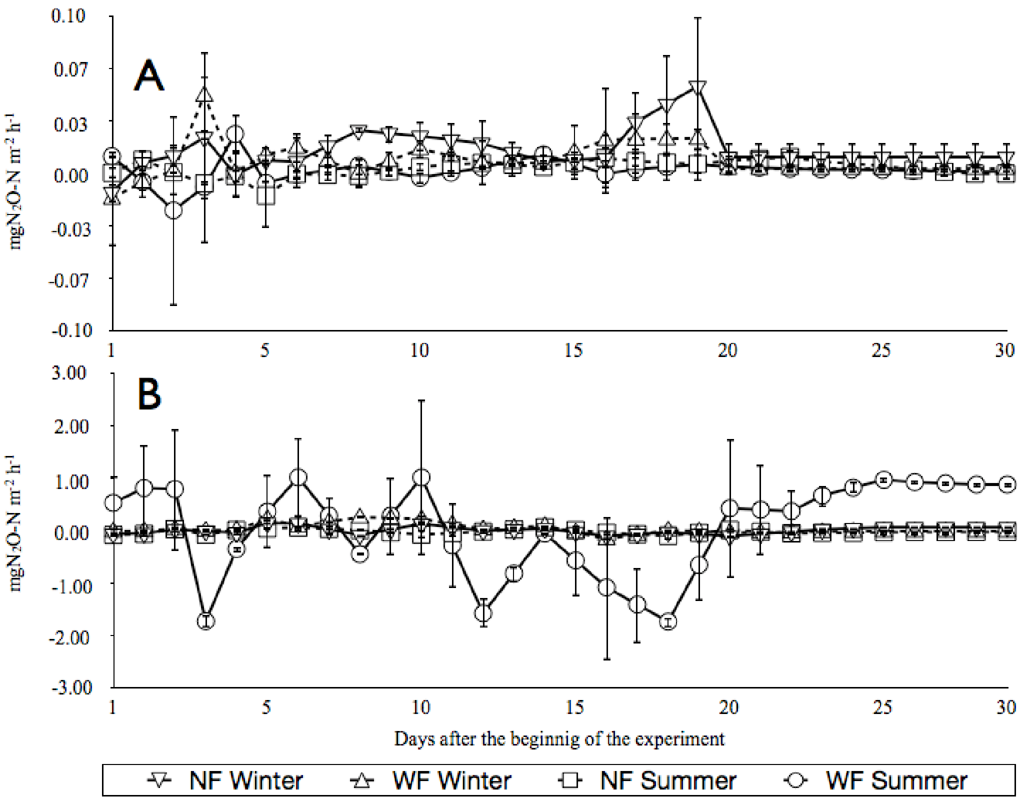

Figure 3 – N_2O emissions from the study sites, in two different seasons. (A) São Paulo state; (B) Rondônia state. The error bars denote the standard deviation

3.4 Discussion

After 30 days under tropical conditions, faeces were completely dry, with only crusts remaining (less than 25% of moisture – Table 2), not representing an important source of GHG anymore. The only exception is summer in RO, were faeces remained wet (81% - Table 2). Although in this situation faeces could still be considered as a source of GHG, our results show that emissions of CH_4 and N_2O from WF decreased to NF levels 5 to 20 days after the beginning of the experiment, with no significant results after this period. Below we explore our results in more detail.

3.4.1 CH_4 emissions

WF treatment was a CH_4 source at both sites, mainly on the first's days of experiment. Prior studies have noted the importance of the first days for CH_4 emission (JARVIS et al., 1995; SAGGAR et al., 2004), when faeces provide ideal conditions for methanogenic microorganisms by maintaining an ideal microhabitat. The differences between the seasons and sites were related with air temperature and faeces moisture. The magnitude of CH_4 emission was strongly influenced by these two characteristics, as shown by the controlled-condition experiment. Emissions in summer were 2.9 and 2.5 times higher than in winter (São Paulo and Rondônia, respectively). Other studies also reported higher emissions in summer and lower in winter season (WILLIAMS, 1993; HOLTER, 1997). According to Yamulki et al. (1999) seasonal effects are significant immediately after the faeces application and negligible thereafter. In our study we found strong seasonal effects during summer at the Rondônia site not only in the beginning, but also during the experiment, with peak emissions of CH_4 in days 7, 11 and 21, mainly influenced by rain events.

In summer, the high temperature combined with rainfall stimulated CH_4 emission. At the São Paulo site, during the summer the faeces dried out quickly (5 days – Table 2) and rain events occurred after crust formation, with no effect on CH_4 emission (Figure 1). Holter (1997) also concluded that the later rewetting of faeces does not lead to a resumption of CH_4 emission. In contrast, at the Rondônia site, rainfall events were distributed over the whole period of experiment (Figure 1). This led to continuously high moisture conditions in the faeces (Table 2), preventing faeces from drying out and releasing the CH_4 trapped within the patch (YAMULKI et al., 1999).

During winter (dry season) the faeces dried rapidly and the emission of CH_4 was restricted until the fourth day. The early formation of crusts reduced the CH_4 emission (YAMULKI et al., 1999) by a factor of 11 to 12 (HUSTED, 1994). In contrast to what we observed, in temperate climates the crust formed in faeces contributes to the preservation of their natural state, acting as a barrier preventing moisture loss, helping to maintain the anaerobic microenvironment and sustaining CH_4 emissions until they were fully dried (SHERLOCK et al., 2003). This has led to prolonged CH_4 emissions, extending for 18 days in Denmark and 20 days in Germany (HOLTER, 1997; FLESSA et al., 2002). Even at temperatures as low as 6°C, substantial CH_4 emissions have still been reported (WILLIAMS, 1993).

Several other factors besides moisture and temperature can influence the CH_4 emission from faeces. The C:N ratio of dung patches is strongly correlated with CH_4 emission (JARVIS et al., 1995), and emissions from intensively managed animals are higher than others in extensive conditions (LODMAN et al., 1993; HUSTED, 1994; JARVIS et al., 1995). Physiological differences between steers raised for beef production and cows raised for milk production also have an impact on CH_4 emission (JARVIS et al., 1995). These interactions could not be evaluated in this study, but the factors cited above indicate that under average Brazilian conditions (steers raised for beef production, low grazing intensity, with no improvements of soil and fed only with grass) faeces can emit less CH_4 than in temperate climates. Despite these characteristics, the interactions between moisture and temperature appear to be more relevant, increasing the emissions in the conditions studied, with results slightly higher than those reported in other studies (see Table 5). In our study we reported the emission factor from faeces in the normal unit (kg CH_4 head^{-1} year^{-1}) to make it comparable with IPCC default. Usually papers do not report emission factors from faeces, just fluxes.

Jarvis et al. (1995) did not find an effect of soil types with respect to CH_4 emission from faeces. The production of CH_4 occurs in anaerobic conditions (ANGEL et al., 2011) and the high variability can be attributed to soil moisture, texture, clay mineralogy temperature, pH, Eh, substrate availability, among others (LE MER; ROGER, 2001). High CH_4 emission obtained from soil (summer RO) may be related with high soil WFPS (Table 2) (YOUNG; RITZ, 2000), a condition that would limit O_2 diffusion into and within the soil. Verchot *et al.* (2000) also showed that pastures in Rondônia can act as sources of CH_4 during the rainy season, in agreement with results published from Costa Rica (VELDKAMP et al., 2001).

Table 5 – Comparison of CH_4 emissions from faeces between this study and other references studies

Reference	Place	Season	Animal	Diet	Emission	Unit
This Study	Brazil (SP)	Winter	Steers	Grass	0.01	$gCH_4\ kgCfaeces^{-1}$
This Study	Brazil (SP)	Summer	Steers	Grass	0.02	$gCH_4\ kgCfaeces^{-1}$
This Study	Brazil (RO)	Winter	Steers	Grass	0.02	$gCH_4\ kgCfaeces^{-1}$
This Study	Brazil (RO)	Summer	Steers	Grass	0.06	$gCH_4\ kgCfaeces^{-1}$
Sherlock et al., 2003	New Zealand	Summer	Dairy cow	?	0.002	$gCH_4\ kgCfaeces^{-1}$
Saggar et al., 2003	New Zealand	-	Dairy cow	?	0.003	$gCH_4\ kgCfaeces^{-1}$
This Study	Brazil (SP)	Winter	Steers	Grass	0.16	$gCH_4\ m^{-2}$
This Study	Brazil (SP)	Summer	Steers	Grass	0.47	$gCH_4\ m^{-2}$
This Study	Brazil (RO)	Winter	Steers	Grass	0.53	$gCH_4\ m^{-2}$
This Study	Brazil (RO)	Summer	Steers	Grass	1.34	$gCH_4\ m^{-2}$
Jarvis et al., 1995	UK	Aumtumn	Dairy cow	Grass-Clover	1.70	$gCH_4\ m^{-2}$
Jarvis et al., 1995	UK	Aumtumn	Calves	High-N grass	1.65	$gCH_4\ m^{-2}$
Jarvis et al., 1995	UK	Aumtumn	Heifers	Grass-Clover	1.14	$gCH_4\ m^{-2}$
Jarvis et al., 1995	UK	Aumtumn	Heifers	Low-N grass	0.42	$gCH_4\ m^{-2}$
Jarvis et al., 1995	UK	Aumtumn	Steers	Grass-Clover	0.41	$gCH_4\ m^{-2}$
Jarvis et al., 1995	UK	Aumtumn	Steers	Low-N grass	0.50	$gCH_4\ m^{-2}$
Jarvis et al., 1995	UK	Aumtumn	Steers	Nil-N grass	0.30	$gCH_4\ m^{-2}$
Yamulki et al., 1999	UK	Summer	Dairy cow	Grass	0.13	$gCH_4\ m^{-2}$
Yamulki et al., 1999	UK	Aumtumn	Dairy cow	Grass	0.93	$gCH_4\ m^{-2}$
Lin et al., 2009	China	Summer 2005	Yak	Grass	0.93	$gCH_4\ m^{-2}$
Lin et al., 2009	China	Summer 2006	Yak	Grass	0.16	$gCH_4\ m^{-2}$

SP: São Paulo state; RO: Rondônia state; UK: United Kingdom; ?: information not available in the paper.

3.4.2 N_2O emissions

Our results agree with those obtained by Allen et al. (1996). High N_2O emissions were found at low temperatures (laboratory experiment), where emissions from the 25°C treatment were higher than 35°C treatment (Table 4), and during winter (field experiment), where emissions were significantly higher than summer emissions at the Rondônia site (Table 3). N_2O emission from faeces in the field was not significantly different from the NF treatment, except for summer at the Rondônia state (Figure 3, Table 3). Unlike in temperate climates faeces in our study were not sources for N_2O (SAGGAR et al., 2004).

One possible explanation for the net negative flux of N_2O from faeces in Rondônia site (Table 3) is the low mineral-N in the soil (Table 1) and the relatively high C/N ratio of the faeces. The decomposition of C from faeces seems to influence N_2O emission (and perhaps reduction), since high emissions of CH_4 were found at the same time as high uptake of N_2O (summer Rondônia – Table 3). The temporary N immobilization during C decomposition can potentially explain this relation (VAN GROENIGEN et al., 2005). Van der Weerden et al. (2011) also reported low emission of N_2O from faeces with high content of N. Another possible explanation is that the anaerobic conditions, ideal for methanogenics Archaea, are not ideal for the denitrification process. Although denitrification occurs in the absence of oxygen, denitrifying bacteria are facultative anaerobes, using nitrate as electron acceptor only when it is strictly necessary. One possible mechanism to explain the N_2O uptake observed is that not enough nitrate was available in the soil, leading denitrifying bacteria to use N_2O as electron acceptor, leading to net N_2O uptake. The emission of N_2O from manure in the field is associated with ammonia-oxidizing bacteria, rather than ammonia-oxidizing Archaea (DI et al., 2010). The Archaea responsible for methanogenics originate from the rumen (FREY et al., 2009) and are much more resilient to environmental stress (temperature, pressure and moisture) because of their membrane formed by dialkyl glycerol ether (DAGE) lipids (CHABAN et al., 2006). Previous studies reported the presence of archaeol, one of the simplest DAGE lipids in bovine faeces (GILL et al., 2010; GILL et al., 2011; MCCARTNEY et al., 2013).

Values obtained for N_2O emission from soil in the São Paulo site were consistent with those reported from New Zealand (DI et al., 2010; GILTRAP et al., 2010; DE KLEIN et al., 2011). One possible reason for higher emission of N_2O from soil in winter is the slow pasture growth at that time, resulting in slow N uptake from the soil. In the summer grass grows faster, with greater N uptake and lower N mineral substrates in soil which can lead to N_2O

emissions (QIU et al., 2010). The factors regulating N_2O consumption in soil are not well understood, but low mineral N and large WFPS, as we found in the Rondônia site (Tables 1 and 2), have been found to favour N_2O consumption (BALL; CLAYTON, 1997; CHAPUIS-LARDY et al., 2007). Low mineral N content was also reported for pastures in Rondônia (VERCHOT et al., 2000). Negative soil fluxes obtained in the Rondônia site fit in the uptake range discussed by Schlesinger (2013) (1 $\mu gN\ m^{-2}\ h^{-1}$ to 207$\mu gN\ m^{-2}\ h^{-1}$). The same author concluded that uptakes larger than 20 $\mu gN\ m^{-2}\ h^{-1}$ are related to wet soils, suggesting that consumption during denitrification is relatively efficient under those conditions. A soil in wet and anaerobic conditions does not necessarily increase N_2O emissions (BALL, 2013). Recent studies have been published reviewing and discussing possible mechanisms of N_2O uptake. Wu et al. (2013) suggested that N_2O production and consumption is regulated by interactions between the O_2 concentration and soil moisture content. More studies in soils with different soil textures, mineral N content, porosity and soil moisture content are recommended to study the relationships between these soil parameters and N_2O consumption and production.

3.5. Conclusion

We showed that under tropical conditions the emission of CH_4 from faeces can be higher than in temperate climates (Table 5). Our results suggest that tropical conditions strongly affect faeces' moisture, and thereby CH_4 emission by maintaining an anaerobic microenvironment within faeces patches. However, although higher than reported emissions in temperate zone, CH_4 emission factors obtained were significantly lower than the IPCC default values. We also conclude that faeces can not be considered as an N_2O source under the conditions of our experiment. This disagrees with observed results from temperate climates and those stated by the IPCC and is likely related to low mineral N in the soil and the relatively high C:N ratio of the faeces, with temporary N immobilization for C decomposition. We also reported net negative fluxes of N_2O. Although the mechanisms of N_2O consumption in soil are not well understood, soil mineral N content seems to be a key factor for regulating N_2O emission and consumption in soil. Our study also showed that in a continental-size country as Brazil, an average emission factor as proposed by IPCC is not the best solution. We strongly recommend studies in other Brazilian regions, such as Caatinga, Cerrado and Pampas for determination of specific emission factors in these regions.

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4. USE OF THE NITRIFICATION INHIBITOR DICYANDIAMIDE (DCD) DOES NOT MITIGATE N_2O EMISSION FROM BOVINE URINE PATCHES UNDER TROPICAL CONDITIONS.

Abstract

Animal production systems are important sources of greenhouse gases (GHGs), especially methane (CH_4) and nitrous oxide (N_2O). GHG emissions from urine patches have been extensively studied in temperate climates, with few studies under tropical conditions. Here we examined the driving factors of N_2O and CH_4 emission from urine patches in the tropics, as well as the role of the nitrification inhibitor DCD (dicyandiamide) in mitigating emissions. We hypothesized that the high temperature and periodical rainfall can increase GHG emissions from urine patches through accelerating mineralization of urine-N. We measured CH_4 and N_2O emissions from beef cattle urine (360 kg N ha^{-1}) in Rondônia state (Brazil, tropical climate), during two different seasons (winter and summer), with and without the application of DCD (10 kg ha^{-1}). No effects of DCD on cumulative N_2O emissions were detected in summer, but DCD retarded the main emission peak. During winter DCD increased N_2O emissions from 10.8 to 39.2 mg N-N_2O m^{-2} ($p \leq 0.05$). Emission factors averaged 0.4% for summer and 0.1% for winter, which is significantly lower than the IPCC default value of 1%. The climate, associated with soil (acidic pH, WFPS and low N content) and plant properties (biological nitrification inhibithion) resulted in a low emission factor. We concluded that the IPCC default emission factor for tropical systems may be reduced, and that the application of DCD is not recommended in such systems.

4.1 Introduction

Animal production systems are important sources of greenhouse gases (GHGs), especially methane (CH_4) and nitrous oxide (N_2O). According to Cerri et al. (2009), livestock is the third largest emitter of greenhouse gases in Brazil, surpassed only by the burning of fossil fuels and deforestation. As deforestation is reducing in the last years, the livestock sector will soon become the second largest source (CERRI et al., 2009). Brazilian beef production is almost exclusively (more than 90%) pasture-based (FERRAZ; FELICIO 2010). The main sources of GHGs in such systems are enteric fermentation, and emissions from urine and faeces deposited in the field. CH_4 emission from enteric fermentation has been studied under Brazilian conditions (PRIMAVESI et al., 2004). Recent studies showed that faeces and urine patches have low emissions of N_2O in Brazilian pastures (MAZZETTO et al., 2014; BARNEZE et al., 2014; LESSA et al., 2014; SORDI et al., 2013), but there is no data regarding the Amazon region, where the area for beef production is increasing in Brazil.

Urea is the main form of N in cattle urine (DIJKSTRA et al., 2013). According to Smith et al. (2005), one urine deposition is equivalent to a local application of 300-600 kg N ha^{-1}. The nitrogen compounds from cattle urine are easy decomposable for microorganisms. Usually, urea-N is quickly hydrolyzed to ammonium (NH_4^+) and subsequently nitrified to nitrate (NO_3^-). Plants can take up both NH_4^+ and NO_3^-, but the deposition rates in urine patches far exceed plant uptake. The excess of N can lead to losses through leaching, ammonia volatilization and N_2O emission (OENEMA et al., 2005), or nitrate can be converted to N_2 through denitrification (WRAGE et al., 2001).

Nitrification inhibitors (NIs), such as dyciandiamide (DCD), have been studied as a means to reduce N_2O emissions. However, both N_2O emissions and the efficiency of NIs are highly variable and depend on several factors, such as soil moisture (DE KLEIN et al., 2011; LUO et al., 2007), soil compaction (VAN GROENIGEN et al., 2005a), temperature (KELLIHER et al., 2008) and climate (QIU et al., 2010). The effect of NIs in urine patches are well documented in temperate and cold climates (DE KLEIN et al., 2011; VAN DER WEERDEN et al., 2011), but not in tropical conditions. This is important, as Kelliher et al. (2008) showed out that DCD degraded faster in warmer temperatures, with half-live lower than 19-20 days above 25^{o}C. This poses as a problem for country inventories of GHG emissions in tropical regions.

In this study we analysed emissions of GHGs from beef cattle urine in Rondônia state (Brazil – tropical climate), during two seasons (winter and summer). We hypothesized that periodical rainfall and high temperature in tropical climates would increase the GHG emission in comparison with other studies in temperate climate. We also hypothesized that DCD will have a lower effect on mitigating N_2O emissions in tropical climates compared to temperate climates due to the typically high temperatures in tropical climate.

4.2 Material and Methods

4.2.1 Experimental set-up

The experiment was carried out from 09 June to 10 July 2012 (winter) and 09 November to 10 December of 2012 (summer) at Agropecuária Nova Vida, Ariquemes, Rondônia state (RO), Brazil (10°10'05''S and 62°49'27''W, 142m a.s.l.). FAO soil classification (FAO 1998) defined the soil as Oxisol, sandy loam texture. Soil properties (upper 10 cm) at the start of the experiment are shown in Table 1. The climate at the site was tropical (Aw - Köppen climatic classification). Meteorological data were recorded at the nearest meteorological station (rainfall and air temperature), which was within 1 km of the field site. The average air temperature and total precipitation were 32°C and 7 mm (winter); 29°C and 250 mm (summer) (Figure 1). The experimental pasture was not grazed by livestock before or during the experiment and had not received any nitrogen fertilizer for five months prior to the experiment.

Table 1 - Soil proprieties (0-10 cm) at the beginning of the two field experiments during winter and summer

	Sand	Clay	Silt	pH	pH	Bulk density	Total C	Total N
	-------------------%------------------			$CaCl_2$	H_2O	g m^{-3}	---------g kg^{-1}---------	
Winter	62.5	30.1	7.4	4.9	5.0	1.6	25.5	2.2
Summer	64.4	24.1	8.3	5.1	5.0	1.6	27.3	3.0

Urine was collected from a group of 10, three year old steers (*Nellore*), with an average weight of 450 kg, directly before the start of the experiments, and thoroughly mixed before application. The steers were grazing pasture (*Brachiaria decumbens)* supplemented with mineral salts. For the experiment, fifteen plots were assigned to three treatments (urine, labeled as "U"; urine with DCD, labeled as "U+DCD"; and a control with no urine and no DCD, labeled as "C") with five replicates, laid out as a randomized complete block design. Each urine sample was applied at the rate of 360 kg N ha^{-1}, which fits with expected content of N from one beef cattle urination (HOOGENDOORN et al., 2010; SMITH et al., 2005). The DCD was applied at a rate of 10 kg ha^{-1}, in accordance with current guidelines (MOIR et al., 2007).

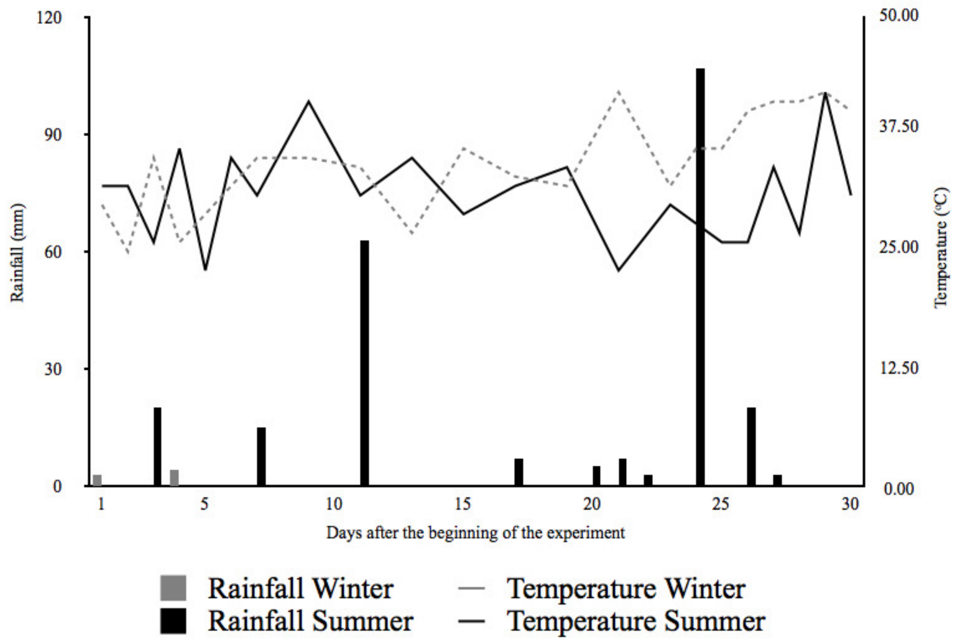

Figure 1 – Climatic data from the studied site, during two different seasons

4.2.2 Gas sampling

A closed static chamber technique (JONES et al., 2005) was used for measuring CH_4 and N_2O emissions. At the field site, non-vented steel chambers (28 cm diameter, 13 cm height) were installed two days before the first sampling. The chambers were inserted to a depth of three cm to ensure an airtight seal. At the time of sampling, lids were placed on top of the chambers and a seal was achieved via water filled groove on the chamber that the lid fitted in to. There were 17 sampling occasions: daily during the first week, followed by three times a week for the next two weeks and twice in the last week of the experiment. Flux measurements were normally carried out between 09:00 and 11:00. Samples were collected at 0, 10 and 20 minutes after the chambers were closed. A 20-ml syringe was used to collect the gas samples from the chambers, which were then placed in pre-evacuated 13 ml headspace vials using a hypodermic needle. The glass vials had a chloro-butyl rubber septum (Chromacol). Samples were analysed for CH_4 and N_2O within seven days after collection by gas chromatography (GC - Shimadzu 2014). Total GHG emissions from the treatments were estimated by calculating cumulative fluxes over an experimental period of 30 days in both studied seasons, assuming linear changes between measurements.

4.2.3 Soil mineral N content

Adjacent to each flux chamber were assigned plots with the same size of the flux chamber, which also received the same urine rate. Soil (0-10 cm) was sampled with an auger on days 1, 7, 14, 21 and 28. Extraction of NH_4^+ and NO_3^- was done using 25g of fresh soil with 2M KCL (ZAMAN et al., 1999). Following centrifugation and filtering, the supernatant was analyzed for mineral N concentration by flow injection analysis (FIAstar 5000 analyzer – Foss - Denmark). Gravimetric moisture content was determined after drying at 105°C for 48 h. Water-filled pore space (WFPS) of the soil was calculated gravimetrically.

4.2.4 Statistical analyses

Data were checked for normal distribution. Both daily CH_4 and N_2O daily fluxes and their cumulative fluxes were compared using one and two-way analysis of variance. Differences between individual treatments were determined using a Tukey test. All significances mentioned in the text were significant at $p \leq 0.05$.

4.3 Results

4.3.1 N_2O Emissions

Average soil WFPS for both seasons is shown in Table 2. U and U+DCD treatments were sources of N_2O, statistically different from the control in both seasons (Table 3). The application of DCD had no effect on cumulative emission, but there was a difference in the N dynamics between the seasons. During winter, U and U+DCD treatments had a peak of the same magnitude, but at different days (day 6 for U+DCD and day 10 for U - Figure 2). During summer, U+DCD had a small peak on day 3, and a main peak on day 5. In the U treatment the main peak occurred early (day 4) and the smaller peak late (day 6) (Figure 3). After 7 days, emissions gradually declined to background levels, but low peaks of U+DCD treatment were found at days 09, 12 and 13. During winter, the cumulative emission of U+DCD treatment was significantly higher than U, but during summer there was no statistical difference (Table 3). Emissions in summer were statistically higher than winter, whereas negative fluxes were observed in the control (Table 3). The calculated emission factors for the studied situations were 0.08 (± 0.01) and 0.13 (± 0.02)% (winter U and U+DCD, respectively) and 0.38 (± 0.05) and 0.37 (± 0.08)% (summer U and U+DCD, respectively). To calculate the average emission factor, we considered the climate of the region with 6 months as summer climate and the other 6 months as winter climate. The average emission factors were 0.23 (± 0.16)% (U treatment) and 0.25 (± 0.14)% (U+DCD treatment).

4.3.2 Mineral N

NH_4^+ levels in the U and U+DCD treatments increased rapidly after the application of urine (day 1), with levels statistically different from soil throughout the experiment, except for the U+DCD treatment on day 30 (winter) (Figure 3). During summer, NH_4^+ content from U and U+DCD treatments were no different from C after 7 days (Figure 3). Soil NO_3^- content peaked at day 22 in the U+DCD treatment during winter and summer (Figure 4). U and U+DCD treatments were statistically higher than soil during all the experiment, except for day 7 (summer) and 15 (winter).

Table 2 – Soil water filled pore space (WFPS - %) in the soil (0-10 cm) at the field experiment during winter and summer.

Winter				
	WFPS (%)		S.D.	C.V.
Day 1	59	aC	7.5	12.8
Day 7	55	aC	6.7	12.1
Day 14	50	aC	7.4	14.8
Day 21	44	bD	5.8	13.3
Day 28	34	cE	4.9	15.3

Summer				
	WFPS (%)		S.D.	C.V.
Day 1	70	bB	7.8	11.2
Day 7	72	bB	8.3	11.5
Day 14	84	aA	8.8	10.4
Day 21	82	aA	10.4	12.6
Day 28	86	aA	9.1	10.5

S.D.: Standard Deviation; C.V.: Coefficient of Variation; Means followed by the same letters in columns are not statistically different (Tukey, p≤0.05). Capital letters show comparison between seasons, while small letter shows comparison inside the season.

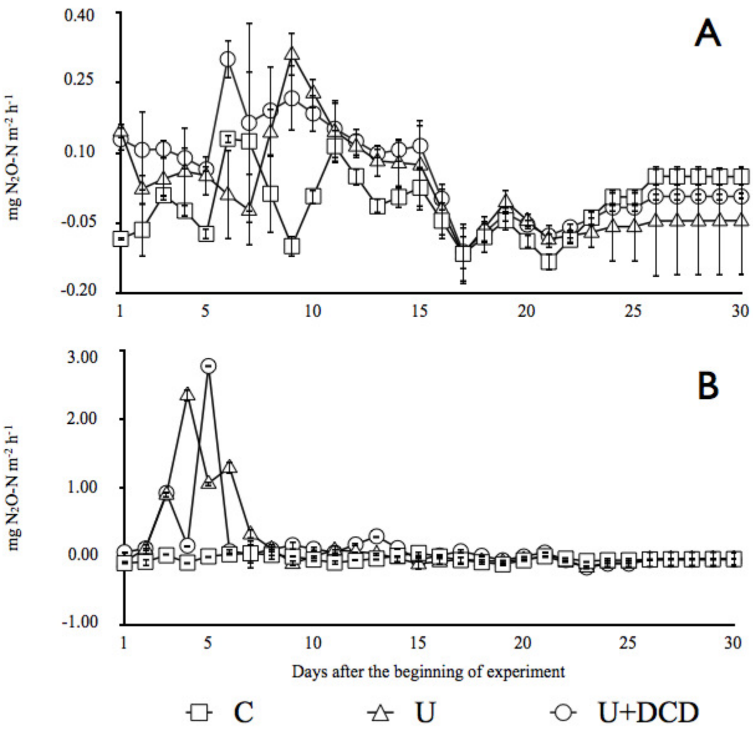

Figure 2 – N_2O emissions from the studied site, in two different seasons. (A) Winter; (B) Summer. C: Control treatment; U: Urine treatment; U+DCD: Urine with DCD treatment. The error bars denote the standard deviation

Table 3 – Cumulative CH_4 and N_2O from urine, urine with DCD and control plots, during two seasons

		N_2O-N				CH_4-C			
		mg m^{-2}							
Season	Treatment	CE		S.D.	C.V.	CE		S.D.	C.V.
Winter	C	-4.6	cD	7.6	136.2	16.7	aA	3.8	22.6
	U	10.8	bC	5.9	54.3	-5.6	bA	4.3	77.0
	U+DCD	39.2	aB	10.7	27.3	12.6	aA	4.2	33.2
Summer	C	-18.8	bE	4.9	26.4	201.8	aA	65.3	32.4
	U	126.2	aA	30.7	24.3	-7.9	aA	5.4	68.4
	U+DCD	109.5	aA	22.5	25.1	33.6	aA	17.5	52.1

C: Control treatment; U: Urine treatment; U+DCD: Urine with DCD application; S.D.: Standard Deviation; C.V.: Coefficient of Variation; CO_2eq: CO_2 equivalent. GWP: Global Warming Potential. Means followed by the same letters in columns are not statistically different (Tukey, p≤0.05). Capital letters show comparison between seasons, while small letter shows comparison inside the season.

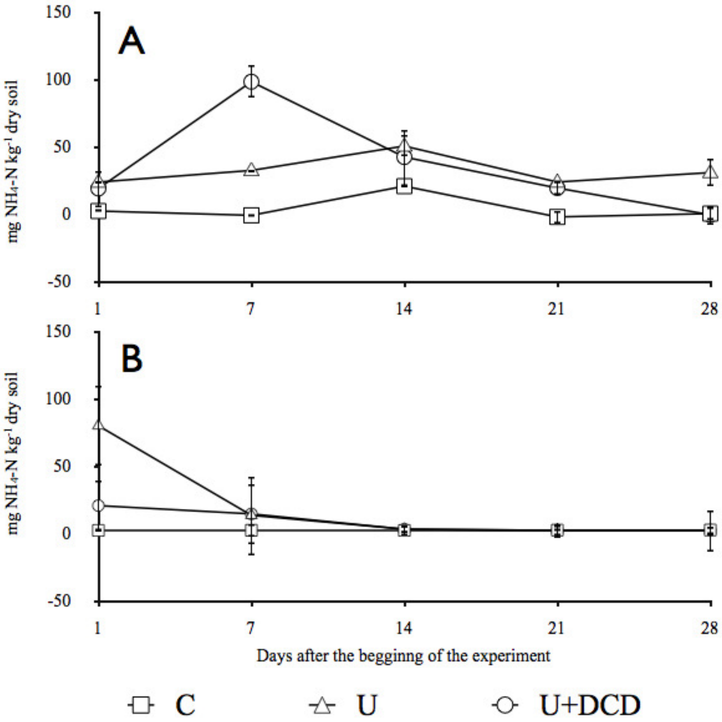

Figure 3 – Ammonium (NH_4^+) content in soil from the studied site, in two different seasons. (A) Winter; (B) Summer; C: Control treatment; U: Urine treatment; U+DCD: Urine with DCD treatment. The error bars denote the standard deviation

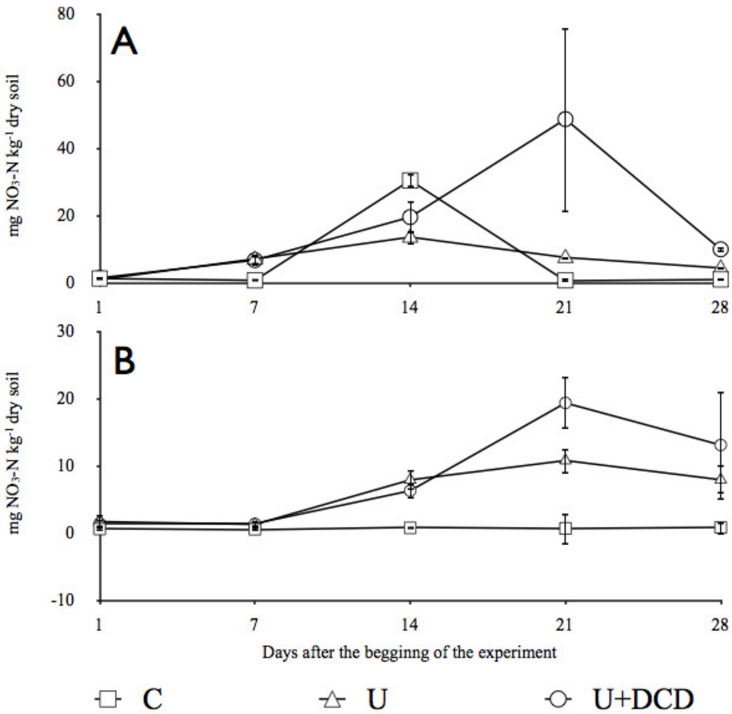

Figure 4 – Nitrate (NO_3^-) content in soil from the studied site, in two different seasons. (A) Winter; (B) Summer. C: Control treatment; U: Urine treatment; U+DCD: Urine with DCD treatment. The error bars denote the standard deviation

4.3.3 CH_4 emission

There was no difference between CH_4 fluxes within both seasons, nor between seasons (Figure 5, Table 3). The U treatment showed uptake of CH_4 in both seasons, but the results were only statistically different from the C treatment during the winter (Table 3).

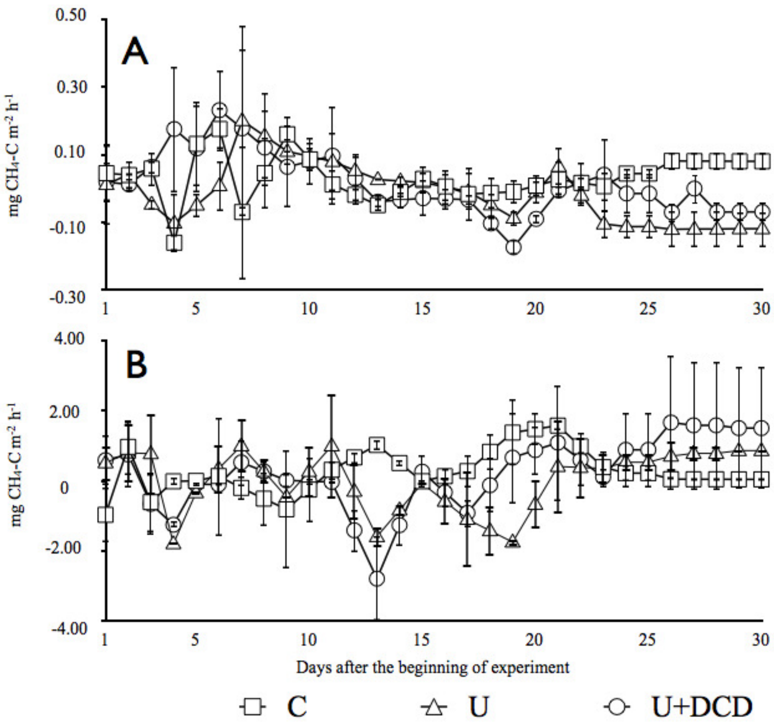

Figure 5 – CH_4 emissions from the studied site, in two different seasons. (A) Winter; (B) Summer. C: Control treatment; U: Urine treatment; U+DCD: Urine with DCD application. The error bars denote the standard deviation

4.4. Discussion

4.4.1 Emission patterns

Our results suggest that application of beef cattle urine does not have any effect on CH_4 emission. Other studies (FLESSA et al., 1996; JARVIS et al., 1995; YAMULKI et al., 1999) also reached similar conclusions. The emission factors for N_2O obtained in this study are significantly lower than the IPCC tier 1 default (1%) and typical values in temperate climates

(0.7 to 0.9%) (GALBALLY et al., 2010; VAN GROENIGEN et al., 2005b). Our summer EF is similar to those obtained in New Zealand in experiments with dairy cows (0.26 to 0.30%) (VAN DER WEERDEN et al., 2011). The winter EF is similar to the lowest EF reported in the literature (0.02 to 0.08%) (LUO et al., 2007). Our average emission factor for both seasons (0.23 ± 0.16%) is similar to the results of Sordi et al. (2013) (0.26%) and Barneze et al. (2014) (0.20%), both in subtropical climate (Brazil). The control treatment was a sink of N_2O in both seasons, but significantly high uptake of N_2O was observed during summer than winter (Table 3). In our study, summer emissions were 11 and 3 times higher than winter emissions (U and U+DCD, respectively – Table 3). As the temperatures were similarly high in both seasons, we suggest that the difference between summer and winter emission is related to difference in WFPS. Emissions of N_2O from urine are high when the WFPS in soil ranges from 60 to 80% (VAN GROENIGEN et al., 2005a), as we found during summer (Table 2). The drier conditions in winter (low WFPS – Table 2) can decrease denitrification rates, as suggested by other authors (DE KLEIN et al., 2003; LUO et al., 2007).

The lower emission factors observed in this study in comparison with other studies in temperate climate may be related with factors related to the plant and soil in the studied region. According to Subbarao et al. (2013), in pastures covered by Brachiaria grasses the flow of nitrogen from NH_4^+ to NO_3^- is restricted by a natural root exudate (brachialactone), and NH_4^+ accumulates in soil. Under such conditions, the nitrification is naturally inhibited. Figure 3 shows that NH_4^+ is significantly higher until day 7 in both U and U+DCD treatment. The soil type is other factor influencing N_2O emissions. According to Brentup et al. (2000), clayed soils tend to show greater emissions than sandy soils due to the small amount of macropores, increasing anaerobic microsites. In sandy soils, more soil moisture is needed to achieve the same amount of N_2O emission observed in clayed soil (NEILL et al., 2005). The presence of O_2 in the sandy soil associated to the low pH observed (Table 1) leads to an inhibition of the nitrous oxide reductase. Low pH values, like we observed in field, leads to low N_2O emissions when the nitrification is the main source of N_2O. Di et al. (2009) showed that ammonia-oxidizing bacteria (AOB) is the main responsible for ammonia oxidation under urine patches. AOB growth is decreased in acidic soils (ROBINSON et al., 2014), potentially reducing the NH_4^+ content in soil. The low availability of N in the soil can also explain the low emission of N_2O by U and U+DCD treatment and the net negative flux in control treatment, even in conditions of high moisture content (DENMEAD et al., 2010).

4.4.2 Effect of DCD

In our study, DCD had no effect on decreasing N_2O emissions. In temperate climates, studies report an average reduction of 57% in N_2O emissions from urine patches by the use of DCD (DE KLEIN et al., 2011). Although there was a decrease of 14% in N_2O emission during summer for the U+DCD treatment, this was not statically different from the U treatment (Table 3). In high temperatures (above 30°C), the half-live of DCD is decreased (DI; CAMERON, 2004). At controlled conditions, Ali et al. (2008) showed that others NIs (nitrapyrin and 3,5- dimethylpyrazole) were ineffective at high temperatures (35°C). Barneze et al. (2015) showed that DCD has a low half-life (seven to ten days) during summer in UK when compared to other studies. The differences observed may be linked to the climate in the region.

The summer season in Rondônia state is warm and wet, with periodical rainfalls. The temperature during the field trial ranged from 25 to 41°C, while the winter was warm and dry, with temperatures ranging between 26 and 42°C (Figure 1). According to Kelliher et al. (2014), there is a linear relationship between the mean soil temperature and DCD half-life (½life = 54 – 1.8*T). The mean soil temperature during the first five days of the experiment on both seasons was 29°C. Extrapolating the relationship by Kelliher et al. (2014), the half-live of DCD in such temperature is 1.8 days. According to Kelliher et al. (2008), the DCD effectiveness depends on how much DCD remains on soil. According to our data, there is near 6% of DCD after the firsts five days of experiment. The different results observed between the seasons must be related to the rainfall. We reported a small reduction (14%) on N_2O emission during summer. The main reason for this reduction can be related to the high temperature (decreasing DCD half-life) associated to the wet conditions due to the periodical rainfall. DCD has no charge and it is soluble in water. In view of this, due to the wet conditions in summer, is likely that most of the DCD applied was leached. The low N_2O peaks observed during days nine, 12 and 13 in the U+DCD treatment may be related to the end of the DCD effect, allowing the nitrification process. The low content of NH_4^+ during summer (Figure 3) must be due to high plant growth in this season. The assimilation of NH_4^+ is energetically more efficient than that of NO_3^- (SALSAC et al., 1987), and plants preferably absorb NH_4^+. As pointed out by Robinson et al. (2014), the less effectiveness of DCD on acidic soils is probably linked to the limited growth of AOB in such conditions, as discussed in section 4.1. During summer, the main source of N_2O is denitrification, especially due to high WFPS (Table 2). The DCD leaching, acidic pH and the low content of NH_4^+ on soil leads to no significant effect of DCD on N_2O emission during summer (Table 3).

During winter, the DCD leaching is not expected, since there were no significant rainfall events and the soil remains with a low WPFS (Table 2). The grass growth during winter is limited by the lack of water and NH_4^+ accumulates on soil. This event, associated with a short response of DCD, leads to a high content of NH_4^+ in U+DCD treatment until day seven. After this period, DCD lost its effect and allow the nitrification, decreasing the NH_4^+ content to background levels in day 14 (Figure 3), and increasing the content of NO_3^- from U+DCD treatment in day 21 (Figure 4). The excess of NO_3^- can be denitrified, leading to more N_2O emission. In this situation, the initial effect of DCD increasing NH_4^+ content on soil was not effective due to the low grass growth in this season. The excess of NH_4^+ led to more N_2O emission. Other possible explanation is a priming effect due to DCD decomposition in soil. DCD is well recognized as a nitrification inhibitor, but it is also a slow release N fertilizer (containing 65% of N) (DI; CAMERON, 2002). The decomposition of DCD, applied at a rate of 10 kg ha^{-1}, results in an increase of 6.5 kg N ha^{-1}. Although this is a relatively small increase, this extra N can cause a priming effect. An increase of N content in the soil may have an important effect on soil microbial communities, especially in a limiting-N environment, leading to increased N mineralization by r-strategist microorganisms (Fontaine et al. 2003), and consequently, nitrous oxide emission. Even after the substrate is exhausted, k-strategist microorganisms may remain active for a while, contributing to soil organic matter decomposition (FONTAINE et al., 2003; KUZYAKOV, 2010) and N_2O emission.

Based on our results, we do not recommend the application of DCD in tropical areas. New studies must aim to the effects of higher doses of DCD during summer in tropical regions, which may show a possible inhibitory effect. As pointed by Ali et al. (2008), more than the recommended rate of NIs must be applied in tropical areas to achieve results similar to those under low temperatures. Other studies must be performed to study in detail the dynamics of DCD in tropical condition, especially during winter, in order to elucidate the fate of DCD in soil. One possible mitigation option is the application of others NIs in association with DCD in order to reduce N losses, as recommended by Zaman and Blennerhasset (2010).

4.5 Conclusion

Our study showed that N_2O emissions from urine patches in tropical conditions are lower than the emissions in temperate climate, and that DCD had no effect on reducing the emissions. The emission factors obtained in our study (0.08 to 0.38% - average 0.23%) are significantly lower than the IPCC default (1%) and others EFs from temperate climate (0.7 to 0.9). The association of several factors, such as climate, WFPS, pH, soil texture and BNI resulted in a lower emission factor than observed in temperate areas The lack of DCD effect must be related to the high temperature in tropical conditions, and the differences observed during the seasons must be due to the water regime in the region. Other strategies to decrease N_2O emissions should also be evaluated, such as increasing the dose of DCD during summer and the use of others NIs associated with DCD.

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5. LIME AND NITROGEN FERTILIZER EFFECTS ON GHG EMISSIONS FROM BRAZILIAN PASTURES

Abstract

Beef production is one of the most important agricultural activities in Brazil. In order to increase production without increasing deforestation, farmers are intensifying breeding and pasture improvements. The main techniques for pasture improvement are the application of lime and nitrogen fertilizer, but these actions can result in emission of greenhouse gases (GHG), as carbon dioxide (CO_2), nitrous oxide (N_2O) and methane (CH_4). We assessed the impact of lime and nitrogen fertilizer application, in field conditions, on GHG emissions in Brazilian pasture located in Rondônia state (South-western of Brazilian Amazon). Agronomic recommended rate of lime and nitrogen fertilizer (LM and NF, respectively) and higher rates, as two times (2LM and 2NF) and four times (4LM and 4NF) the recommended rate were applied. A control treatment (C) with no lime or no fertilizer was also analysed. The application of lime resulted in higher CO_2 emissions and increased soil pH when compared with control treatment, but there was no difference between rates ($p<0.05$). Nitrogen fertilizer application resulted in high N_2O emissions, especially in the 4NF treatment (15.4 mg N-N_2O m^{-2}). We found no differences between NF and 2NF treatments (3.9 and -7.0 mg N-N_2O m^{-2}, respectively), but all treatments were different from control (-18.7 mg N-N_2O m^{-2}). The emission of CH_4 was also significantly higher in the 4NF treatment (669.6 mg C-CH_4 m^{-2}) than control, NF and 2NF treatments (201.8, 376.6, 452.4 mg C-CH_4 m^{-2}, respectively). The application of intensification techniques increased GHG emission from pastures. However, the subsequent higher forage yield leads to lower N_2O emission per kg of forage (161.4, 58.5 and 106.5 mg N_2O kg DM^{-1} for NF, 2NF and 4NF, respectively) and slightly higher CH_4 emission per kg of forage (1.2, 1.2 and 1.4 mg CH_4 g DM^{-1}, for NF, 2NF and 4NF, respectively). Under the conditions of this study the best practice is the application of recommended agronomic rates of lime, since higher rates do not further influence the soil pH, and the application of 100 kg N ha^{-1} (2NF treatment) due to low emissions of CH_4 and N_2O per kg of forage.

5.1 Introduction

Brazil is the second largest beef exporter, responsible for 15% of beef production worldwide (FAO, 2012). The typical system of beef production is pasture-based, predominantly occurring on unimproved pastures. Pastures occupy three-quarters of the national agricultural area, about 180 million hectares (IBGE, 2011). The Brazilian government predicts an increase of internal consumption and exports of beef for the next 10 years. In order to meet this high demand, Brazilian farmers must develop a more intensive system, rather than increase deforestation (MARTHA et al., 2012). This intensive system must have higher beef production per unit area, with low emissions of greenhouse gas (GHG). If farmers do not adopt sustainable options for pasture intensification, deforestation could be increased, and consequently, could increase GHG emissions. The improvement of the whole system of beef production is a key component to reduce emissions from all relevant sources, including land use, land use change and livestock (BOWMAN et al., 2012).

In order to improve beef systems, some intensification methods must be applied, such as the application of lime and nitrogen fertilizer. Liming is commonly used in Brazil due to the large extent of acidic soils, with low content of calcium (RITCHEY et al., 1982) and aluminum toxicity (PAVAN et al., 1984), and may represent an important source of non-biogenic CO_2 (BERNOUX et al., 2003). The main limiting-nutrients for grass growth in Brazilian conditions are phosphorus (P) and nitrogen (N). The application of fertilizer enhances the availability of N to the plant and microorganisms, but an excess of N can result in nitrous oxide (N_2O) emissions through nitrification and denitrification processes (WRAGE et al., 2001). The effect of N fertilizer on N_2O emission and lime application on carbon dioxide (CO_2) emission are well reported in the literature (BEEK et al., 2009; BIASI et al., 2008; DUMALE JR et al., 2011; JASSAL et al., 2011). However, there are no studies in tropical climates regarding lime application, and only one (DE MORAIS et al., 2013) regarding N fertilizer application on pastures.

We measured the effect of lime application on CO_2 emission and the effect of N fertilizer application on N_2O and methane (CH_4) emissions. To simulate the intensification practices, we tested the effect of the application of the recommended level of lime and fertilizer in GHG emission. There is anecdotal evidence that farmers usually apply more than the recommended rate. Therefore, we also tested higher amounts of lime and nitrogen fertilizer to verify the changes in emission patterns and the impact of such techniques in GHG emission.

5.2 Material and Methods

5.2.1 Lime

The experiment was carried out on a permanent pasture. The pasture was not grazed by livestock before or during the experiment and had not received any N fertilizer for one year prior to the experiment. The experiment was carried out from 09 November to 10 December of 2012 (summer) at Agropecuária Nova Vida, Rondônia state, Brazil (10º10'05''S 62º and 49'27''W) under tropical climatic conditions (Aw - Köppen climatic classification). Soil is classified as Oxisol according to FAO classification (FAO, 1998), and its texture is sandy loam. Soil properties (upper 10 cm) at the start of the experiment were: total N of 0.20%, total C of 2.50%, pH of 4.9 and bulk density of 1.50 Mg m^{-3}. Meteorological data were recorded at the nearest meteorological station (rainfall and air temperature), which was within 1 km of the field sites. The average air temperature and total precipitation were 29^{o}C (varying from 25.4 to 33.2 ^{o}C) and 250 mm (varying from 3 to 107mm) (Figure 1). Those conditions are representative of the summer season of the southwestern part of the Brazilian Amazon.

Lime was applied in soil right before the beginning of the sampling period. The experiment consisted of a soil-only control (C) plus four treatments: soil-$CaCO_3$ with lime applied at three different rates: 1; 2 and 4 ton $CaCO_3$ ha^{-1}, namely agronomic recommended rate (LM); two times the agronomic rate (2LM) and four times the agronomic rate (4LM), respectively, with five replicates each. A closed dynamic soil CO_2 flux system (LI-COR 8100, model 8100-101) was used for measuring CO_2 emission. The system was attached to a survey chamber (PVC 10-cm diameter, volume 0.84L) inserted into the soil two days before the beginning of the experiment. Soil respiration rates were computed using LI-8100 file viewer application software, calculated as a linear CO_2 increase using 1-s readings and a closure time of 2 minutes, discarding the initial 15-s mixing period after closure. Chambers were sampled daily during the first week, three times a week in the next two weeks and twice in last week of the experiment. There were 17 sampling occasions. At the end of the experiment the soil from each chamber was collected to check the pH.

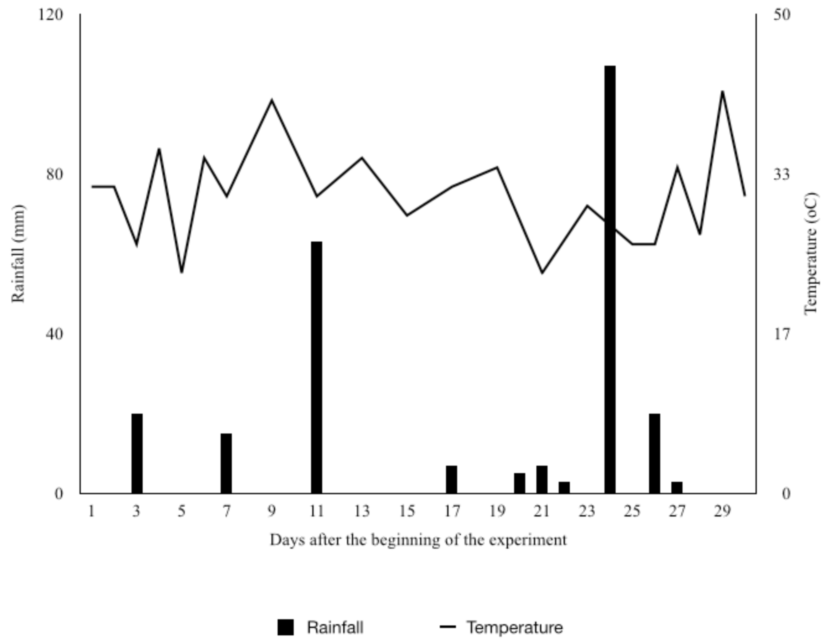

Figure 1 – Climatic data from the study site (Rondônia, southwestern Brazilian Amazon, Brazil)

5.2.2 Fertilizer

The experiment with fertilizer application occurred at the same conditions (local and date) as the lime field experiment. We studied the application of ammonium nitrate (NH_4NO_3) in rates 0, 50, 100 and 200 kg N ha^{-1} (treatments C, NF, 2NF and 4NF, respectively), with five replicates to each treatment, in a randomized complete block design. The closed static chamber technique (JONES et al., 2005) was used for collecting gas samples. At the field, not vented chambers (28 cm diameter, 13 cm height) were placed two days before collecting gas samples. The chambers were inserted to a depth of up to 3 cm to ensure an airtight seal. The volume enclosed by the chamber was approximately 11L. At the time of sampling, lids were placed on top of the chambers and a seal was achieved via water filled groove on the chamber that the lid fitted in to. Gas sampling was normally carried out between 10:00 and 14:00. Samples were collected at 0, 10 and 20 minutes after the chamber were closed. A 20-ml syringe was used to collect the gas samples from the chambers, which were then placed in pre-evacuated 13 ml headspace vials using a hypodermic needle. The glass vials had a chloro-butyl rubber septum (Chromacol). The pre-evacuation was carried out using a vacuum pump. The samples were analysed as soon as possible after collection by gas chromatography (GC - Shimadzu 2014).

Adjacent to each gas chamber were designated plots that also received the same fertilizer rate. Soil (0-10 cm) was sampled on days 1, 7, 14, 21 and 28. Soil mineral N content was determined by extraction with 2 M KCl with a 1:2 ratio of soil and extractant (BREMMER; KEENEY, 1966). Soil extracts were filtered and stored at 4°C. Concentrations of NH_4^+ and NO_3^- in the extracts were determined by automated flow injection analysis (FIA) (RUZICKA; HANSEN, 1981). Gravimetric moisture content was determined after drying at 105°C for 48 h. Pastures from each chamber were cut at 4–5 cm height at the end of the experiment. The green matter was transferred to a pre-weighed paper bag and dried at 70°C for 1 week. After 1 week of drying, dry pasture weight was recorded.

5.2.3 Statistical analyses

Total GHG emission was estimated by calculating cumulative fluxes over an experimental period of 30 days. Data were verified for normal distribution and treatment means for daily CO_2, N_2O and CH_4 fluxes and cumulative fluxes over the period of the experiment were compared using one-way analysis of variance. To determine the statistical significance of the mean differences, Tukey tests were carried out at 0.05 probability level.

5.3 Results

5.3.1 Lime

We observed background emissions from soil during all the experiment. There was an increase in CO_2 emissions in the plots where lime was applied, especially from treatments 2LM and 4LM (Figure 2). Emission from LM treatment was similar to the control, with no statistical difference (Table 1). All lime-treated plots had an increase in pH, significantly different from soil without lime (Table 2).

5.3.2 Fertilizer

Emissions were variable over the study period (Figure 3). The majority of the emissions were found in the first two weeks of the experiment. After that, emissions returned to background levels (Figure 3). Our results showed that the application of N fertilizer, independent of the rate, increases N_2O emission, changing the pasture status from a net sink to a net source of N_2O (Table 3). The emission of CH_4 from fertilized plots was higher than the control, but statistical difference was only found in the 4NF treatment (Figure 5 - Table 3), increasing even further the net emission of GHG from pastures.

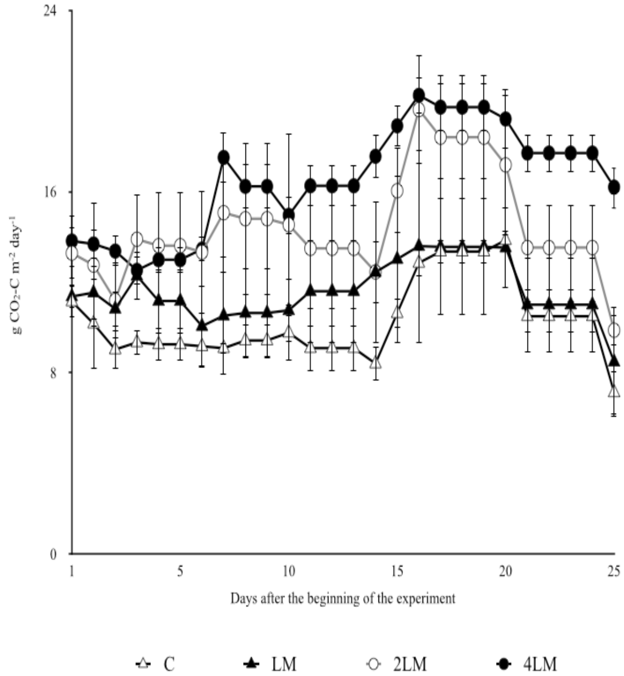

Figure 2 – CO_2 emissions from lime experiment. C: no application of lime; LM: application of the agronomic recommended dose of lime; 2LM: two times the application of the agronomic recommended dose of lime; 4LM: four times the application of the agronomic recommended dose of lime. The error bars denote the standard deviation

Table 1 – Cumulative CO_2 emissions from field study

	CO_2 g m^{-2}			
Treatment	CE		S.D.	C.V.
C	267.3	c	10.4	3.9
LM	291.6	bc	12.7	4.4
2LM	343.3	ab	9.8	2.6
4LM	413.5	a	48.1	11.6

C: no application of lime; LM: application of the agronomic recommended dose of lime; 2LM: two times the application of the agronomic recommended dose of lime; 4LM: four times the application of the agronomic recommended dose of lime; Standard Deviation; C.V.: Coefficient of Variation; Means followed by the same letters in columns are not statistically different (Tukey, $p \leq 0.05$).

Table 2 – Change in soil pH due to lime application

Treatment	pH Mean		S.D.	C.V.
C	4.9	b	0.1	2.4
LM	5.7	a	0.3	6.1
2LM	5.8	a	0.8	13.0
4LM	5.8	a	0.5	9.3

C: no application of lime; LM: application of the agronomic recommended dose of lime; 2LM: two times the application of the agronomic recommended dose of lime; 4LM: four times the application of the agronomic recommended dose of lime; Standard Deviation; C.V.: Coefficient of Variation; Means followed by the same letters in columns are not statistically different (Tukey, p≤0.05).

NH_4^+ levels in the NF treatment increased rapidly after the application nitrogen fertilizer, with levels statistically different from soil throughout the experiment until day 21. (Figure 4). The NH_4^+ content from 2NF and 4NF treatments increased after day 7, and remained high until day 21 (Figure 4). Soil NO_3^- content from all treatments was significantly higher than control during all experiment.

The forage yield increased due to N fertilizer application (Table 4). The application of intensification techniques increases GHG emission from pastures, but the increase of forage yield leads to lower N_2O emission per kg of forage (161.4, 58.5 and 106.5 mg N_2O kg Dry matter^{-1} for NF, 2NF and 4NF, respectively) and slightly higher CH_4 emission per kg of forage (1.2, 1.2 and 1.4 mg CH_4 g Dry matter^{-1}, for NF, 2NF and 4NF, respectively). The net CO_2eq emission was 132, 87 and 118 g CO_2eq kg Dry mater^{-1}, to NF, 2NF and 4NF treatments, respectively.

5.4 Discussion

5.4.1 Lime

Lime is a C source for microorganisms in soil, increasing basal respiration (KEMMITT et al., 2006; STADDON et al., 2003). The peaks of CO_2 observed in the lasts days may have been due to stimulation of microbial biomass by the increased availability of labile organic carbon, which often increases after application of lime (CHAN et al., 2007; MOTAVALLI et al., 1995) Once this material is exhausted; respiration becomes limited by a lack of available substrate (FUENTES et al., 2006) or nitrogen (BORKEN; BRUMME, 1997). According to this hypothesis, a higher rate of lime application should result in a higher

CO_2 emission, as reported in our study (Table 1). We cannot conclude that 100% of the carbon applied as lime was emitted as CO_2, since we did not used isotopic analysis of carbon. Different ecosystems seem to respond differently to liming (BIASI et al., 2008). It is generally acknowledged that liming increases soil CO_2 emission, especially in laboratory studies using soils from grasslands (HOPKINS, 1997; KEMMITT et al., 2006; SHAH et al., 1990; WEBSTER et al., 2000), forest (ANDERSSON; NILSSON, 2001; MURAKAMI et al., 2005) and crops (FUENTES et al., 2006; HAYNES; SWIFT, 1988). Biasi et al. (2008) showed that more than 50% of CO_2 emitted in the early stage of laboratory incubation analyses are derived from the added lime. There are few field-scale studies, and they are restricted to forest soils (BORKEN; BRUMME, 1997; BORKEN et al., 2000; YAVITT et al., 1995). Carbon dioxide evolves when lime is dissolved in water (PAGE et al., 2009).

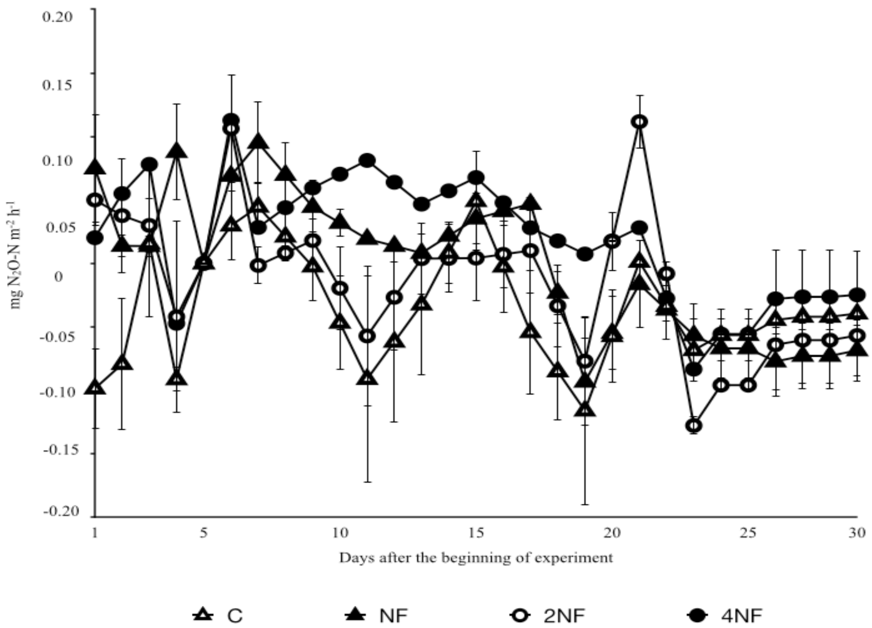

Figure 3 – N_2O emissions from the studied site. C: Control; NF: application of 50 kg N ha^{-1}; 2NF: application of 100 kg N ha^{-1}; 4NF: application of 200 kg N ha^{-1}. The error bars denote the standard deviation

The increase of soil pH is a common effect of lime application to soil (FUENTES et al., 2006; KEMMITT et al., 2006), but the consequences are not well explained. Another possible reason for the increase of CO_2 emission with lime application is the shift in microbial community. The majority of microorganisms in soil are dormant, waiting for suitable conditions. Liming alters the microbial population, decreasing microbial biomass adapted to acidic conditions (PAWLETT et al., 2008). The change of pH offers a selective advantage to the remaining microbial community, resulting in an increase in microbial biomass (CHAGNON et al., 2001) and soil respiration (FUENTES et al., 2006). In limed soils, the microbial community is more metabolically diverse (SHAH et al., 1990; WEBSTER et al., 2000), being able to metabolize more substrates, thereby increasing CO_2 emission. Our study was not designed to observe such microbial changes, but this hypothesis seems to fit better with our results. Soil moisture and temperature are not limiting for decomposition in tropical climates, so soil pH becomes a major factor regulating the decomposition of organic materials in this environment (BERNOUX et al., 2003; MOTAVALLI et al., 1995).

According to our results, the best practice is the application of the recommended rate of lime. The use of the recommended rate showed the same efficiency in change soil pH as the more intensive treatments (2LM and 4LM), with no difference in CO_2 emission using less lime (Table 1 and 2).

Table 3 – Cumulative N_2O and CH_4 emissions from field study

	N-N_2O mg m^{-2}				C-CH_4 mg m^{-2}			
Treatment	CE		S.D.	C.V.	CE		S.D.	C.V.
C	-18.7	c	4.9	26.4	201.8	b	136.6	67.7
NF	3.9	b	1.2	26.9	376.6	ab	121.6	32.3
2NF	-7.0	b	0.4	6.1	452.4	ab	19.4	4.3
4NF	15.4	a	6.2	40.2	669.6	a	85.9	12.8

C: Control; NF: application of 50 kg N ha^{-1}; 2NF: application of 100 kg N ha^{-1}; 4NF: application of 200 kg N ha^{-1}. S.D.: Standard Deviation; C.V.: Coefficient of Variation; Means followed by the same letters in columns are not statistically different (Tukey, $p \leq 0.05$).

5.4.2 Fertilizer

The increase in N_2O emission was expected, since the application of ammonium nitrate increases the availability of nitrate in soil (Figure 4). The available N can be quickly taken up by plants or lost as N_2O in a few days (JONES et al., 2007). According to Subbarao et al. (2013), in pastures covered by *Brachiarria* grasses the flow of nitrogen from NH_4^+ to NO_3^- is restricted by a natural root exudate (brachialactone), and NH_4^+ accumulates in soil. In such situation, the nitrification is naturally inhibited. Due to this biological nitrification inhibition (BNI), the N dynamics was different in the different treatments. When low N was applied to soil (NF treatment), the NH_4^+ concentration increased rapidly and than decreased after the first week, while NO_3^- concentration peaked 14 days after the beginning of the experiment and than decreased to background levels (Figure 4). The assimilation of NH_4^+ is energetically more efficient than that of NO_3^- (SALSAC et al., 1987). In such situation, the BNI kept NH_4^+ in soil and the plant gradually absorbed this nutrient, while the excess was nitrified to NO_3^-, resulting in small peaks of N_2O. The plant could also absorb the NO_3^-, resulting in low NO_3^- concentration in NF treatment and low denitrification. In such situation, the nitrification seems to be the main source of N_2O. When the higher dose of ammonium nitrate was applied in soil (4NF treatment), the plant quickly absorbed preferably the NH_4^+ resulting in an excess of N in form of NO_3^- in day 7. The excess of NO_3^- was denitrified to N_2, resulting in N_2O peaks. Due to the high amount of N applied, NH_4^+ accumulated in soil after 7 days, when BNI kept it concentration until day 21. During this time, NH_4^+ was gradually absorbed and nitrified to NO_3^-, until reach background levels after 28 days (Figure 4). In this case, the denitrification was the main process leading to high N_2O emissions due to the excess of NO_3^-. The 2NF treatment shows middle-term behaviour of the two processes described above. When both nitrification and denitrification were important (2NF treatment) we found the lower N_2O emission. The relationship between N input and cumulative N_2O emission was not linear, as reported by Cardenas et al. (2010).

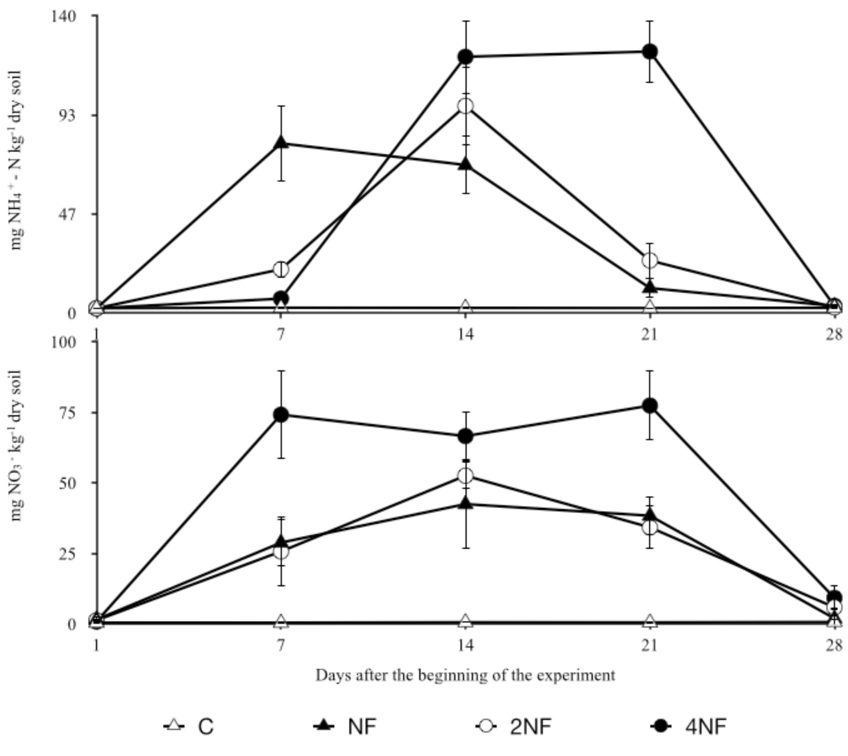

Figure 4 – Ammonium (NH_4^+) and Nitrate (NO_3^-) content in soil from the studied site. C: Control; NF: application of 50 kg N ha^{-1}; 2NF: application of 100 kg N ha^{-1}; 4NF: application of 200 kg N ha^{-1}. The error bars denote the standard deviation

Table 4 – Effect of nitrogen fertilizer application on yield (kg dry matter ha^{-1})

	Yield			
Treatment	Mean		S.D.	C.V.
C	750	d	80.0	10.6
NF	1356	c	93.4	6.9
2NF	1960	b	230.3	11.7
4NF	3247	a	259.6	8.0

C: Control; NF: application of 50 kg N ha^{-1}; 2NF: application of 100 kg N ha^{-1}; 4NF: application of 200 kg N ha^{-1}. S.D.: Standard Deviation; C.V.: Coefficient of Variation; Means followed by the same letters in columns are not statistically different (Tukey, $p \leq 0.05$).

There is a lack of studies regarding N_2O emission from fertilizer in tropical pastures. The study of de Morais et al. (2013) was conducted in Rio de Janeiro, with a different source of N to the grass (urea). Dobbie and Smith (2003) and Jones et al. (2007) reported that N_2O fluxes are larger when ammonium nitrate is used as an N source compared to other mineral or organic fertilizers. Cardenas et al. (2010) showed higher N_2O emissions in wetter regions of UK. Soil temperature influences N_2O emissions, increasing the nitrification and denitrification processes (SKIBA et al., 1998). These differences in N source, rainfall and temperature can significantly change the N dynamics in soil. Therefore, our recommendation is that the EFs for Brazilian conditions must be specific for the different sources of N and regions or biomes.

According to our results, the 2NF treatment (100 kg N ha^{-1}) seems the best option, since it increases the forage yield (Table 4), decreases N_2O emissions and had no effect in the CH_4 emission (Table 3), resulting in the lower CO_2eq emission per kg of Dry matter. Jassal et al. (2011) also concluded that N inputs decrease CH_4 uptakes by soil.

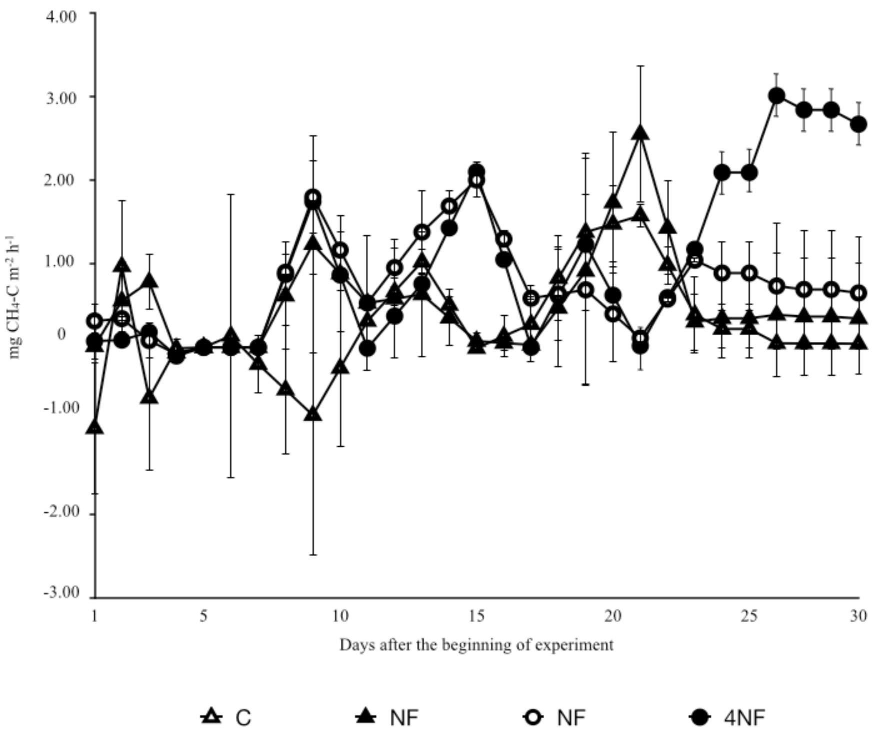

Figure 5 – CH_4 emissions from the studied site. C: Control; NF: application of 50 kg N ha^{-1}; 2NF: application of 100 kg N ha^{-1}; 4NF: application of 200 kg N ha^{-1}. The error bars denote the standard deviation

5.5 Conclusion

The application of intensification techniques resulted in an increase in GHG emission under the studied conditions. Our study showed that the application of lime and N fertilizer at doses above the recommended rates could increase the GHG emission even further. For lime application, there was an increase in CO_2 emission, but increasing lime rate did not further increase the soil pH. For N fertilizer application, the emissions of N_2O and CH_4 significantly increased at the higher rate used. In order to improve grassland management, we recommend the application of the agronomic recommended rate of lime and a maximum fertilizer rate of 100 kg N ha^{-1}.

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6. IMPROVED PASTURE AND HERD MANAGEMENT TO REDUCE GREENHOUSE GAS EMISSIONS FROM A BRAZILIAN BEEF PRODUCTION SYSTEM

Abstract

Brazilian farms produce 15% of the world's beef, and consequently they are an important source of greenhouse gases (GHG). The beef sector faces the challenge to meet the increasing demand without further increasing GHG emissions. To reduce the pressure on forests it is essential that farmers are provided with sustainable options of intensification of pasture growth and cattle production. The improvement of the whole system of beef production is a key component to reduce emissions from all relevant sources, like land use, land use change and livestock. The main objective was to quantify the GHG gas emissions of different beef production systems in Brazil. Therefore we developed a whole farm model that allows us to calculate GHG emissions from all-important sources for a beef production system in Brazil. We simulated the intensification in several steps. The simulation starts with a baseline system (Extensive scenario), and continues with five steps of intensification. The main differences between the scenarios are related to pasture management, i.e. continuous or rotational grazing, pasture condition, stocking rate, use of lime and fertilizer, and irrigation; and animal performance, i.e. calving interval, age at first calving, conception rate, total life time until slaughter, and genetic improvement. Compared to the baseline Extensive scenario, the pasture area decreased up to 92% in the most intensified system (Improved scenario), while beef production nearly doubled. Intensification increased the number of calves, steers and heifers, decreased the total production cycle time and the slaughter age of the steers. Overall, the emissions of GHGs were lower with increasing intensification. The emissions of CH_4 decreased, while the emissions of N_2O and CO_2 increased with the intensification methods due to N fertilizer and lime application. The intensification of beef production, through improved pasture and herd management, reduces the GHG emissions per unit of beef from 2 to 57%. The beef production in intensified systems required less time and area, and may thus help to alleviate the pressure on forests.

6.1 Introduction

Beef production systems are an important source of greenhouse gases (GHG) through emission of carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O). The emissions arise from enteric fermentation, manure handling, nitrogen fertilizer applications and soils. The Brazilian cattle herd is one of the largest in the world, responsible for 15% of beef production worldwide (FAO, 2012). The national beef production has increased six fold between 1950 and 2006. From 1950 until 1985 this increase was mainly related to and increase in land use, rather than productivity (MARTHA et al., 2012). Livestock farming in Brazil expanded into areas with poor infrastructure and depleted by the intensive production of crops (VEIGA et al., 2004). From 1985 until now the Brazilian beef production increased due to improved technologies, such as genetics, health and forage management. Although the pasture area decreased (MARTHA et al., 2012), the average stocking rate is still around one animal unit (AU) per ha. In Brazil, pastures occupy about 180 million hectares, approximately three-quarters of the national agricultural area (IBGE, 2006).

There are at least two major challenges for the Brazilian beef production in the near future. First, competition for land will further increase over the next ten years. The agricultural area needs to expand by 20 million ha to meet the growing needs of food, feed and biofuels. This expansion should preferably occur through the use of degraded pastures. Furthermore, there are also projections of increased demand for beef in the order of 2.5% per year until 2017-2018 (BRASIL, 2010), increasing the pressure on pastureland as well. The second challenge is to increase beef production without further increasing GHG emissions. According to Cerri et al. (2009), livestock is the third largest emitter of greenhouse gases in Brazil, surpassed only by the burning of fossil fuels and deforestation. As deforestation is reducing in the last years, the livestock sector will soon become the second largest source of GHG. Brazil already has established GHG mitigation targets. In June 2010, the Low Carbon Agriculture Program (Programa ABC) was established. The program aims to stimulate the development and adoption of more sustainable agricultural practices that reduce GHG emissions. Brazil has recently committed itself for a reduction of 36% in GHG emissions (BRASIL, 2010), and the livestock sector is one of the main targets.

According to Carpentier et al. (2000), continuation of deforestation is a dead end, as it will further increase GHG emissions. The intensification of current production system seems to be a sensible strategy to achieve the goals of beef supply on a 20 million ha smaller area than the currently used area (GOUVELLO, 2010; MARTHA et al., 2012). The improvement of the whole system of beef production is a key component to reduce emissions from all relevant sources, like land use, land use change and livestock (BOWMAN et al., 2012).

The main hypothesis of this study is that the intensification of beef production, through improved pasture and herd management, can reduce GHG emissions per unit of beef. The main objective of the present paper was to quantify the GHG gas emissions of different beef production systems in Brazil. Therefore we developed a whole farm model that allows us to calculate GHG emissions from all-important sources for a beef production system in Brazil. The model is able to simulate different scenarios with varying intensities of pasture and herd management, and thus calculate the GHG emission in different intensification scenarios.

6.2 Material and Methods

6.2.1 Climate and Geographical location of the simulated farm

Brazil is a continental-size country, and beef systems are very different from north to south. The increase in beef production in the northern (Amazon) region is partly driven by the increase in pasture area, which is different from other regions where the productivity is the main driver for the increased beef production (MARTHA et al., 2012). We focused our study on the North region because the improvement of the beef production system will represent an important prerequisite to reduce deforestation, especially in the Amazon region. The hypothetical farm used in our simulation was located in Rondônia state. The predominant soil is classified as Oxisol (FAO, 1998). The average annual temperature is 25.5ºC, with an average annual precipitation of 2,200 mm. The climate is defined as tropical (Aw - Köppen climatic classification), with a well-defined rainy season (summer), from November to March, and a dry season (winter), from June to September.

6.2.2 Farm type

The basic representative system is a Brazilian farm in an area of *Brachiaria spp.* grass, where the complete beef production cycle, from calf to finished adult steer of slaughter weight, is carried out (Figure 1). Most of the slaughtered animals (60%) for beef production are four years old steers, with an average live carcass weight of 450 kg (FERRAZ; FELICIO, 2010). As 90% of cattle are raised under this type of extensive conditions (ANUALPEC, 2010), we do not consider feedlots. All the scenarios are finished on pasture, with no manure handling.

6.2.3 Emission sources

We considered the following GHG sources (Table 1): CH_4 emissions from enteric fermentation and cattle manure; direct N_2O emissions from urine, fertilizer, as well as indirect emissions through leaching and volatilization; and CO_2 emissions from lime. Off farm emissions from the production of fertilizer, lime and other products were not considered in this study. We calculated the emissions considering the soil carbon (C) in “steady-state”, i.e. no C loss or sequestration, as well as in a “no-steady-state” condition, i.e. C loss and sequestration depending on pasture management (MAIA et al., 2009). We used best available emission factors, either from local measurements (Chapters 2 and 3) or from the IPCC (Table 1). All emissions were expressed as CO_2 equivalents (Global Warming Potential of 23 for CH_4, 296 for N_2O and 1 for CO_2). Emissions are expressed in kg CO_2eq for the whole farm and per kg beef. The model was developed in Microsoft Excel (MICROSOFT CORPORATION, 2000). Results of single-factor linear regression analysis are expressed as the square of the Pearson product moment correlation coefficient (r^2).

Table 1- Sources of emission considered and emission factors

Source	Emission Factor	Unit	References
CH_4			
Enteric fermentation			
Cows	63	kg CH_4 head^{-1} year^{-1}	BRASIL, 2010
Bulls	55	kg CH_4 head^{-1} year^{-1}	BRASIL, 2010
Calves	42	kg CH_4 head^{-1} year^{-1}	BRASIL, 2010
Steers	42	kg CH_4 head^{-1} year^{-1}	BRASIL, 2010
Heifers	61	kg CH_4 head^{-1} year^{-1}	BRASIL, 2010
Faeces	0.08	kg CH_4 head^{-1} year^{-1}	Chapter 2
N_2O			
Urine	0.0023	kg N_2O-N kg N applied^{-1}	Chapter 3
Fertilizer	0.01	kg N_2O-N kg N applied^{-1}	IPCC, 2006
Indirect			
Frac volatilization	0.1	kg NH_3-N kg N applied^{-1}	IPCC, 2006
Volatilization	0.01	kg N_2O-N kg NH_3-N applied^{-1}	IPCC, 2006
Frac leaching	0.3	kg NO_3^- N kg N applied^{-1}	IPCC, 2006
Leaching	0.0075	kg N_2O-N kg NO_3^-N^{-1}	IPCC, 2006
CO_2			
Lime	0.44	kg CO_2 kg lime applied^{-1}	IPCC, 2006
C loss			
Degraded	0.28	Mg C ha^{-1} year^{-1}	MAIA et al., 2009
Nominal	0.03	Mg C ha^{-1} year^{-1}	MAIA et al., 2009
Improved	- 0.61	Mg C ha^{-1} year^{-1}	MAIA et al., 2009

6.2.4 Scenarios

We have defined five different scenarios based on information from farm surveys, studies published in international and Brazilian journals and statistical data. The simulated scenarios are representations of real systems in Brazil. We simulated a stable herd, with a replacement rate of 20%. The simulation starts with 100 cows and four bulls (Mother Herd), and ends after six calving cycles (life-span of a cow), when the offspring of the 6^{th} cycle is slaughtered. We used the same approach as Beauchemin et al. (2010) in order to evaluate the whole beef production system.

In tropical regions, calves are usually weaned at seven months (SANTOS et al., 2011). The stocking rates were based on the pasture dry matter (DM) production, considering the management applied in each scenario (MARTHA et al., 2003). The pasture area for each simulated scenario was based on the stocking rate. The pasture condition was classified from degraded to improved, based on (MAIA et al., 2009). The production system was analysed separately for different components: Mother Herd (cows and bulls), Calves (calves from birth until the weaning phase), Fattening (steers and heifers from weaning phase until slaughter) and Replacing Cows (heifers raised for replacement of culled cows) (Figure 1). Cows are usually culled from the herd when they consistently wean light calves (ELER et al., 2008). This division allowed us to explore the results from the intensification practices for each component.

We simulated the intensification in several steps. The simulation starts with a baseline system (Extensive scenario), and continues over five steps of intensification (Figure 2). The main differences between the scenarios (Table 2) are related to pasture management, i.e. continuous or rotational grazing, pasture condition, stocking rate, use of lime and fertilizer, and irrigation; and animal performance, i.e. calving interval, age at first calving, conception rate, total life time until slaughter, and genetic improvement. In the following section we describe in detail the intensification steps and how they affect the beef production system.

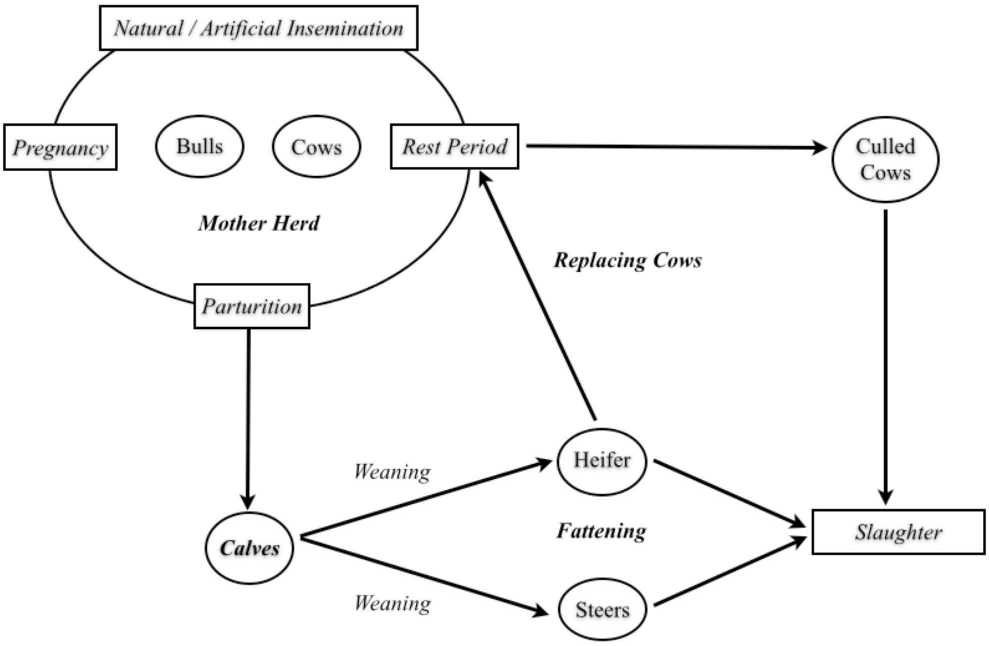

Figure 1 – Full cycle of beef production simulated in this study. The four main components are bold. Circles delimit the animals present in the cycle, while rectangles delimit the main processes

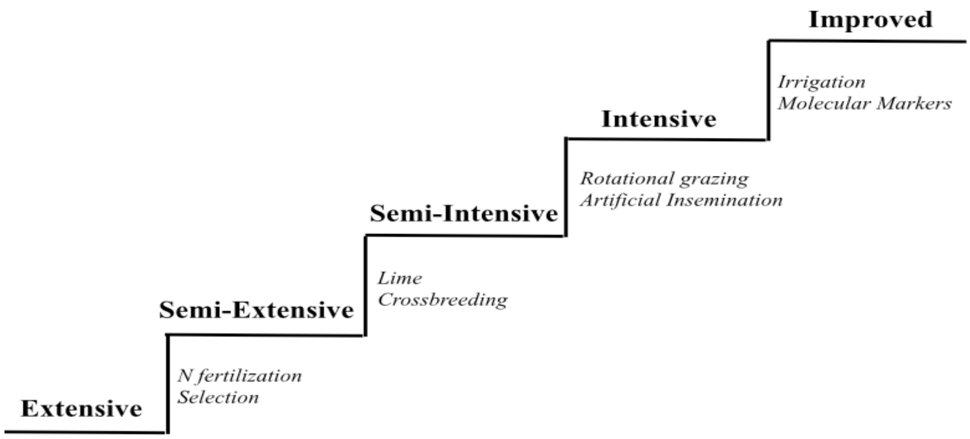

Figure 2 – Intensification steps simulated in this study

Table 2 – Main differences between the simulated scenarios

	Unit	Extensive	Semi-Extensive	Semi-Intensive	Intensive	Improved
			Pasture Management			
Irrigation	-	No	No	No	No	Yes
Management	-	No	Low	Medium	High	Very High
Pasture	-	Degraded	Nominal	Nominal	Improved	Improved
Grazing	-	Continuous	Continuous	Continuous	Rotational	Rotational
Lime	ton ha^{-1} $2years^{-1}$	0	0	1	1	2
Fertilizer	kg N ha^{-1} $year^{-1}$	0	50	100	200	400
			Animals Performance			
Stocking rate	AU ha^{-1}	0.5	1	2	3	6
Cows						
Calving interval	months	15	15	12	12	12
Age at first calving	months	36	30	24	18	18
Cow cycle	years	6	6	6	6	6
Conception rate	%	50	60	70	75	80
Calves						
Birth weight	kg	40	40	40	40	40
Weaning weight	kg	180	180	180	180	180
Slaughter weight	kg	460	460	460	460	460
Steers						
Age at slaughter	months	48	42	36	30	24
Weaning time	months	7	7	7	7	7
Growing time	months	41	35	29	23	17
Growth	kg day^{-1}	0.22	0.26	0.32	0.40	0.54
Mortality						
Calves	%	8	7	5	5	5
Adults	%	2	2	1	1	1
			Beef Production			
Carcass	%	50	50	52	54	55

6.2.4.1 Pasture and Animal Management

The first scenario (Extensive) is a *Brachiaria. spp.* grass pasture managed under continuous grazing, with a low plant cover invaded by non-palatable native species, no pasture improvement and low stocking rate. These characteristics, associated with the lack of pasture management, lead to a decline in forage yield due to a decrease in soil fertility (DE OLIVEIRA et al., 2004). Such characteristics can lead to erosion and degradation, with potential C loss (MAIA et al., 2009). In most native pastures of Brazil there is a predominance of the C4 species, which have a relatively low growth and low feed quality during the winter (EUCLIDES FILHO, 2004; NABINGER et al., 2009). This can lead to low weight gain during the dry season (winter), or even weight loss in some situations. The result of this poor performance is the late slaughter of cattle, close to 48 months. This extensive and low-productivity agriculture is considered as a driver of deforestation (CARPENTIER et al., 2000).

The challenge under tropical conditions is to increase the forage utilization period, reducing seasonality. The first factor for intensification in our study was to use nitrogen (N) fertilizer during the rainy season (EUCLIDES et al., 2008). Brambilla et al. (2012) showed that the production of forage is increased by N application, since N is one of the major limiting elements in Brazilian conditions. The application of N fertilizer increases forage accumulation, feed quality (ELEJALDE et al., 2012; SANTOS et al., 2013) and consequently the stocking rate (FAGUNDES et al., 2003). The Brazilian average use of N fertilizer on pastures is low, 6 kg N ha^{-1} $year^{-1}$ (DUBEUX JÚNIOR et al., 2006) In our study we simulated the application of 50, 100, 200 and 400 kg N ha^{-1} $year^{-1}$ for the Semi-Intensive, Semi-Extensive, Intensive and Improved scenarios, respectively.

The second step for intensification occurs in the Semi-Intensive scenario, when lime is applied to pasture (at least 3 months) before the nitrogen fertilizer. Brazilian soils are acid (BERNOUX et al., 2003), with a low content of calcium (RITCHEY et al., 1982) and aluminum toxicity (PAVAN et al., 1984). Lime is added to neutralize the acidifying effect of the fertilizer and correct the natural acidity. The soil pH regulates soil nutrient bioavailability, plant productivity and structure (WHITE; ROBSON, 1989). The increase in soil pH due to lime application favors the grass growth. The amount of lime recommended is defined by soil analyses, and depends on the total N fertilizer use. In our study we considered an application of one ton ha^{-1} (scenarios Semi-Intensive and Intensive) and two ton ha^{-1} (scenario Improved).

The third step for intensification, in the Intensive scenario, is the adoption of a rotational grazing system. The partition of the pasture in paddocks increases the utilization of pasture forage by concentrating animals and allows pasture to rest and recover from grazing. Managed systems in rotational grazing with fertilized grass are able to produce a high amount of dry matter throughout the year (DA SILVA; JÚNIOR, 2007). IN the rotational grazing system, the period of harvest and rumination decreases, with more time to rest (MANZANO et al., 2007). The average growth rate increases with pasture improvement and better management, which allows earlier slaughter of animals, raised exclusively on pasture (Table 2) (PARIS et al., 2009).

The fourth step for intensification (Improved scenario) is the use of irrigation systems during the winter. The northern region has smaller temperature variations during the year and the seasonality of forage production is related to the irregularity of rainfall. The irrigation of pasture in the dry period can boost the effects of N application and reduce the seasonality of forage production, with uniform production and quality throughout the year (QUEIROZ et al., 2012).

6.2.4.2 Animal improvements

Nellore (zebu cattle) is the dominant beef breed in Brazil (FERRAZ; FELICIO, 2010), well adapted to local conditions. The genetic improvement of the herd is simulated in in several steps, analogous to the pasture improvement in the previous section.

According to Machado et al. (2003), the Nellore breed has a high endogamy, which can result in a decrease of heterozygosis and loss of lustiness. The first step is the selection for low endogamy, which allows the formation of animals with better performance. De Alencar et al. (1999) points out that the average age of first calving for Nellore is 36 months. The age at first calving can also be improved through selection (Table 2). The second step is the use of crossbreeding, which can reduce the calving interval (PEROTTO et al., 2006) and the age at first calving (DE ALENCAR et al., 1999) (Table 2). Furthermore, crossbreeding can also increase the beef production, increasing the beef yield per animal (THEUNISSEN et al., 2013). In more intensive systems, the artificial insemination (AI) (third step) is often used. This technic increases the conception rate to more than 70%. Between 15 and 40% of bulls have problems in soundness (CHACON et al., 1999) and there is the possibility of infertility in the dominant bull (AMANN et al., 2000). The AI excludes those possibilities, also helping in prevention of diseases and injury (VISHWANATH, 2003). Another important advantage is herd standardization, where animals have similar characteristics and performance. The last step of intensification in our study is the use of molecular markers for selection of specific genes or groups of genes. In this technic, characteristics other than phenotypical can be selected, such as parentage determination, genetic distance determination, sex determination and gene mapping. (CURI et al., 2010; DUNNER et al., 2013).

6.3 Results

The technical results of the beef production system improved significantly with increasing intensification. Compared to the baseline Extensive scenario, the pasture area decreased up to 92% in the improved scenario, while beef production nearly doubled (Table 3). Intensification increased the number of calves, steers and heifers (Table 4) decreased the total time spent to complete the six cycles and the slaughter age of the steers (Table 1).

Overall, the emissions of GHGs were lower with increasing intensification. The emissions of CH_4 decreased, while the emissions of N_2O and CO_2 increased with the intensification methods due to N fertilizer and lime application.

6.3.1 Steady-state

The total farm emission varies from 21 to 49 kg CO_2eq kg^{-1} beef (Table 5). The first step of intensification (Semi-extensive) only showed a small reduction in GHG emissions. Further intensification (steps 2, 3 and 4 – Figure 2) resulted in a significant reduction of GHG emission (26, 39 and 57% of reduction, respectively – Table 5). In all scenarios, the main source of GHGs was enteric fermentation, ranging from 64 to 98% of total emission (Table 6). In the more intensified systems other sources also became relevant, such as N fertilizer (direct and indirect) and lime (Table 6).

The emission of CO_2eq from the Complete Cycle was mainly related to CH_4 (r^2=0.81) and N_2O (r^2=0.35) emission (Table 3). There was no significant correlation with the CO_2 emission (r^2=-0.02). The Mother Herd and the Replacing Cows components showed the same pattern as the Complete Cycle. The main driver in total CO_2eq emission was CH_4 from enteric fermentation (r^2=0.95 and 0.69, respectively – Table 3), with a low correlation of total CO_2eq emission with N_2O and CO_2. The emission from the two other components (Calves and Fattening) was regulated especially by CH_4 (r^2= 0.99 and 0.93, respectively), but N_2O (r^2=0.72 and 0.79, respectively) and CO_2 (r^2=0.81 and 0.73, respectively) were important in total GHG emission (Table 3).

The components of the beef production system had different responses to intensification. With increasing intensification the GHG emission was more homogeneous allocated to the components (Table 7). As CH_4 was the main driver in the Mother Herd component, the reduction of the time spent in the total simulated cycle resulted in a lower GHG emission and a lower contribution of the Mother Herd component to the total emission in more intensified systems (Table 7). The higher number of calves in the more intensified systems (Table 5) resulted in a higher contribution of the Calves component to the total emission (Table 7) due to higher emission of GHG from enteric fermentation. The opposite occurred in the Replacing Cows component, were the decrease in lifetime of the heifers resulted in a lower contribution to the total emission of this component (Table 7). Even with the decrease in the steer's lifetime in more intensified systems, the Fattening component increased its contribution to total emission (Table 7). The main reason for this is that this component required a larger area than the other components (Table 3), and consequently the higher GHG emissions from applied nitrogen fertilizer and lime was allocated to the Fattening component (Tables 3 and 6).

Table 3 – GHG emission, beef production and total area for the simulated scenarios (by complete cycle and components). CO_2eq emissions are show in steady-state condition (ST) and no steady-state (NST)

	CO_2eq - ST	CO_2eq - NST	CH_4	N_2O	CO_2	C loss	Beef Production	Area
	Mg							ha
Complete Cycle								
Extensive	2911	10570	124	0.2	0	2087	60	608
Semi-Extensive	3505	4172	125	2.9	0	121	72	343
Semi-Intensive	3354	3832	114	2.3	351	48	93	168
Intensive	3046	1428	106	2.4	187	-518	103	95
Improved	2405	1753	74	2.2	177	-245	112	48
Mother Herd								
Extensive	1881	4530	80	0	0	722	-	210
Semi-Extensive	2047	2183	77	0.3	0	37	-	105
Semi-Intensive	1765	1820	62	0.3	110	15	-	53
Intensive	1699	993	59	0.3	69	-193	-	35
Improved	1221	887	39	0.3	66	-91	-	18
Calves								
Extensive	183	939	8	0	0	203	-	60
Semi-Extensive	305	352	10	1.1	0	13	-	36
Semi-Intensive	387	409	11	0.9	44	6	-	21
Intensive	411	129	12	0.8	28	-77	-	14
Improved	379	246	11	0.7	26	-36	-	7
Fattening								
Extensive	498	3051	21	0	0	696	33	203
Semi-Extensive	922	1092	26	0.6	0	46	45	131
Semi-Intensive	1104	1173	31	0.4	138	19	64	66
Intensive	921	282	27	0.3	63	-174	74	32
Improved	818	516	23	0.3	59	-82	82	16
Replacing Cows								
Extensive	348	2050	15	0.1	0	464	27	135
Semi-Extensive	453	545	12	2.8	0	25	27	71
Semi-Intensive	399	429	10	2.2	59	8	28	28
Intensive	299	4	7	2.4	27	-75	30	14
Improved	233	104	5	2.2	25	-35	30	7

ST: steady-state simulation; NST: no-steady-state simulation.

Table 4 – General outputs of the model: total number of animals and total time of simulation

	Extensive	Semi-Extensive	Semi-Intensive	Intensive	Improved
Total number (heads)					
Cows	100	100	100	100	100
Bulls	4	4	4	4	4
Calves	276	335	399	428	456
Steers	130	157	194	207	221
Heifers	12	40	75	89	102
Replacing cows	119	119	119	119	119
Total Time (6 cycles - years)	12.3	11.7	9.5	9.0	8.5

Table 5 – GHG emission per unit of beef (kg CO_2eq kg^{-1}) in the simulated scenarios

Steady-state

		*Reduction (%)				
	Emission	Extensive	Semi-Extensive	Semi-Intensive	Intensive	Improved
Extensive (baseline)	49	-	-	-	-	-
Semi-Extensive	48	-2	-	-	-	-
Semi-Intensive	36	-26	-25	-	-	-
Intensive	30	-39	-37	-16	-	-
Improved	21	-57	-56	-41	-30	-

No-steady-state

		*Reduction (%)				
	Emission	Extensive	Semi-Extensive	Semi-Intensive	Intensive	Improved
Extensive (baseline)	177	-	-	-	-	-
Semi-Extensive	58	-67	-	-	-	-
Semi-Intensive	41	-77	-29	-	-	-
Intensive	14	-92	-75	-66	-	-
Improved	16	-91	-72	-61	+14	-

* Reduction of GHG emission related to the previous scenario.

Table 6 – Relative proportion of the various sources of GHG emission (CO_2eq, % of total emission).

	Extensive	Semi-Extensive	Semi-Intensive	Intensive	Improved
Enteric Fermentation	98	76	69	70	65
Fertilizer	0	17	14	17	20
Fertilizer (indirect)	0	6	5	5	6
Lime	0	0	10	6	7
Urine	1	1	1	0	1
Urine (Indirect)	1	0	1	0	1
Faeces	0	0	0	0	0
Total	100	100	110	100	100

Table 7 – Breakdown of total GHG emission (CO_2eq, % of total emission) per component.

	Extensive	Semi-Extensive	Semi-Intensive	Intensive	Improved
Mother Herd	65	55	48	51	46
Calves	6	8	11	12	14
Growing	17	25	30	28	31
Replacing Cows	12	12	11	9	9
Total	100	100	100	100	100

6.3.2 No steady-state

Including C sequestration has a huge impact on the total GHG emission, with values ranging from 14 to 177 kg CO_2eq kg^{-1} beef (no-steady-state) (Table 5). The intensification process showed a significant reduction in GHG emission in all studied steps, except for the step fromthe Intensive to the improved scenario (Table 5). The main driver to explain the GHG emission from the scenarios was the C loss or sequestration (r^2=0.99) (Table 3). The better management of the pasture decreased the C loss, especially in the Intensive and Improved scenarios (Table 3). Pastures can act as important C sinks through C sequestration (SOUSSANA et al., 2007; MAIA et al., 2009). The C loss or sequestration is related to the pasture condition and the total area. The Intensive scenario required more than twice the area of the improved scenario (Table 3), and consequently, had more C sequestration (Table 3). Both Intensive and Improved scenarios were classified as “improved pasture”, with the same rate of C sequestration (Table 2), which is the main reason why the intensity of GHG emission from the Intensive scenario was smaller than the Improved. This last result is rather arbitrary, as it depends on our assumptions.

6.4 Discussion

Our results confirmed the initial hypothesis, as the more intensified systems showed a lower emission of CO_2eq per unit of beef (Table 5). Despite these reductions, the beef systems remain net sources of GHGs. Our results showed that the decrease in CH_4 emission outweighs the impact of N_2O and CO_2 from application of nitrogen fertilizer and lime, decreasing the total CO_2eq emission in the more intensified systems.

In recent years, there have been an increasing number of studies concerning GHG emission from the beef production systems. Our results fit in the range of 8.4 to 34.9 kg CO_2eq kg^{-1} carcass (CROSSON et al., 2011), except the Extensive and Semi-Extensive scenario (49 and 48 kg CO_2eq kg^{-1} beef, respectively). These values are lower than the FAO estimation for South America and the global average (60 and 55 kg CO_2eq kg^{-1} beef, respectively) (GERBER et al., 2013). It is difficult to compare the results from these studies, since there are different emission factors used and system boundaries assumed. Most of these studies don’t take into account the C loss or sequestration. Rather than to establish the absolute value of GHG emission, our study aimed to simulate and discuss the effects of intensification methods on GHG emission.

Our results show that intensified systems produce more beef on less area and in less time, with lower emission of GHG per unit of beef (Tables 4 and 5). Although our study was not designed to calculate the implementation price of intensification, the results suggest a faster return of investment for farmers. Beyond that, the Brazilian government has already disposed U$2 billion through 14,000 financial credit contracts to farmers that adopt technologies for pasture recuperation, no tillage systems, plant forest, among others (BRASIL, PROGRAMA ABC, 2010). Financial incentives like this can accelerate the intensification process of Brazilian beef production.

The intensification steps simulated in this study can be considered as combined sets of mitigation options, aiming to improve the efficiency of pasture and animal production.. According to our results, the implementation of these intensification technics can mitigate from 2 to 57% of the GHG emission (Table 5). These are important and relevant results especially in the Amazon area, where intensification practices can prevent deforestation. An increase in productivity of the beef system spared 73 million hectares in the Amazon region from 1996 to 2006 (MARTHA et al., 2012). This land-saving effect can be even higher with more intensification practices.

The simulated intensification resulted in a more homogenous distribution of emissions between the system components (Table 6). This creates more targets for specific mitigation actions, such as precision farming (STEINFELD; GERBER, 2010). The manure handling is an important source of emission through anaerobic decomposition, especially in those countries were the manure is stored (SOMMER et al., 2007). In our study the emission from faeces and urine (direct and indirect) accounted for less than 2% in most of the simulated scenarios due to the lack of manure handling in the Brazilian pasture-based system (Table 7). Other authors also stated that the enteric fermentation is the main source of emission in beef systems (BEAUCHEMIN et al., 2010; FOLEY et al., 2011). Our study confirms that enteric fermentation is an important source of GHG in Brazilian conditions and targeted mitigation strategies should be considered, for instance improved forage digestibility (UDO et al., 2011; GERBER et al., 2013).

6.5 Conclusion

The intensification of beef production, through improved pasture and herd management reduces the GHG emissions per unit of beef. The intensification scenarios simulated in this study can be considered as important mitigation options, reducing the GHG emission per unit beef from 2 to 57%. The beef production in intensified systems required less time and area, and may thus help to alleviate the pressure on forests.

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7. FINAL CONSIDERATIONS

The aim of this thesis was to determinate emission factors and calculate the carbon footprint of beef production under extensive management in Brazil.

The results obtained here show that the emission of GHG is higly affected by temperature and climate, as observed by the GHG emission from faeces. The climate significantly influenced the dynamics of faeces decomposition and, consequently, the GHG emission. Other important result was that DCD did not result in reduction of N_2O emission. The climate again had important role in this result. The fast decomposition of DCD due to the warm climate led to no effect in N_2O emission. New studies must focus on the fate of DCD in soil to determinate what mechanisms led to increse N_2O emissions during summer, but the use of DCD under tropical climate is not recommended. Others strategies must be evaluated to act as mitigation options.

The use of lime significantly increased the emission of CO_2, but the reccomended rate of application is enough to perform the desireble effect in soil (increase pH) with low impact on GHG emission. Nitrogen fertilizer application had an strong effect on N_2O emission, but the increase in forage yield led to low emission of N_2O per kg of forage. This result was important during the simulation study, where the intensification steps led to an increase in N_2O and CO_2 emission, but decreased the CH_4 emission. The reduction of CH_4 from enteric feermentation due to the lower length in animal life outweight the increase in N_2O and CO_2 emission, leading to lower carbon footprint in the improved scenarios.

The main conclusion of this thesis is that the beef production in Brazilian conditions can be improved by intensification technics without influence the GHG emission. The land-saving effect from intensification practices is important to decrease deforestation of new areas, resulting in more sustainable production.